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NECESSARY WIND TUNNEL TESTS CONDITIONS OF PROPER TWO- AND THREE-DIMENSIONAL MEASUREMENTS

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Abstract

In this article, the conditions to be met by a two- and three dimensional wind tunnel tests in order to ensure their correctness are presented. First of all, they relate to the flow similarity between the real and wind tunnel conditions. This similarity enforces a wind tunnel calibration, a proper design and manufacturing of the tested models, a proper research, as well as processing of obtained test data including the usage of the wind tunnel corrections. In this work, the majority of these conditions were presented but in particular, the influence of the wind tunnel corrections on the tested models aerodynamic characteristics is consider. The two-dimensional airfoil studies and three-dimensional aircraft model balance investigation were performed in two low speed wind tunnels of a different sizes of theirs test section. The wind tunnel tests were performed in two Institute of Aviation low speed wind tunnels, namely in the wind tunnel T-1 (of the 1.5 m diameter test section) and in the wind tunnel T-3 (of the 5 m diameter test section), at the same undisturbed velocity, V∞ = 40 m/s. The comparison of the lift coefficient characteristic obtained in two different wind tunnels using the same two and three-dimensional models and same measurement techniques enabled to discuss the problem of necessity of the wind tunnel corrections usage.

Keywords: *applied aerodynamics, tests reliability, aerodynamic measurements*

1. Introduction

In many research centres, universities, as well as in some industrial centres different types of wind tunnels are used where the fluid flow (usually air) around the tested subjects enables to determine their aerodynamic characteristics. In Poland, exist over 70 such research devices [1]. In majority, these are low speed wind tunnels, i.e. operating in the area of non-compressible flows, what corresponds to the Mach numbers $M < 0.4$. An important issue is to ensure the reliability of the obtained wind tunnel tests results, i.e. their compliance with real conditions. The achievement of this goal requires both proper preparation of the research device, which is a wind tunnel (i.e. calibration of this tunnel) as well as a proper performance of the research.

The calibration of the wind tunnel is based on ensuring a proper quality of the air stream in the wind tunnel test section or the test chamber, what should be understood as meeting the requirements presented in the literature [2-9]. Essentially, these requirements relate to three parameters of the air stream, namely the homogeneity of undisturbed flow velocity, the small angle of the air stream deflection in relation to the wind tunnel axis of symmetry, as well as the low level of the airflow turbulence. The requirements of wind tunnels air stream quality described in the literature are as follows:

1. The irregularity of the air velocity distribution (ΔV), $\Delta V \le 0.2$-0.3% V(average velocity).
2. The irregularity of the angle of the air stream deflection in relation to the wind tunnel axis of symmetry in vertical ($\Delta\alpha \le 0.1^{o}$) and horizontal ($\Delta\beta \le 0.1^{o}$) wind tunnel plane of symmetry.
3. The turbulence level (τ):
   – wind tunnels for testing laminar-turbulent transition, $\tau \le 0.05\%$,
   – wind tunnels for testing aircrafts, $\tau \le 0.5\%$,
   – wind tunnels for testing ground facilities $\tau \le 1.0\%$.

A proper performance of the wind tunnel tests, which is the second important factor ensuring the reliability of the obtained tests results, are based first of all on correct modelling of aerodynamic phenomena. This can be achieved by maintaining the similarity of flows between real and wind tunnel tests conditions. In tunnel research, in which one has to deal with phenomena of a quasi-stationary character, the most important issue is to preserve the similarity of flows taking into account the air viscosity, air compressibility and also the geometrical similarity of the tested models with the real objects. This similarity is maintained if the same values of the Reynolds and Mach numbers in real and modelled flow are maintained. Like in many cases, the fulfilment of those requirements is impossible to realize in wind tunnel tests. Conditions of these experiments are selected in such a way that the influence of the mentioned similarity numbers on the tested models aerodynamic characteristics is as small as possible.

A proper performance of the wind tunnel tests results in a compliance of the obtained wind tunnel tests with a real conditions. This can be achieved by the correctness of a series of actions performed during the experiment beginning from the model design and preparation to the tests and ending with the tests results processing. Consideration of the influence on the accuracy of measurements each of these actions separately would be extremely laborious and complicated. For these reasons, in the practice of wind tunnel testing to assess the correctness of the test results two methods are used. The first of these methods is based on testing of the calibration models whose aerodynamic characteristics are known and published in literature. Comparison of the calibration test results with those from literature gives an information about a reliability of the obtained tests results in the wind tunnel. The second method relies on investigation of any model in a different wind tunnels, characterized by a different sizes of theirs test section, but in the same flow conditions.

In the article, the second method was used and the two-dimensional NACA 0012 airfoil model and three-dimensional Tu-154M aircraft model were tested. The wind tunnel tests were performed in two Institute of Aviation low speed wind tunnels T-1 (of the 1.5 m diameter test section) and T-3 (of the 5 m diameter test section), at the same undisturbed velocity, $V\infty = 40$ m/s.

2. Experimental setup and instrumentation

2.1. Wind tunnels

The experimental wind tunnel tests discussed in the article were performed in two Institute of Aviation low speed wind tunnels, namely in the wind tunnel T-1 and in the wind tunnel T-3.

The T-1 wind tunnel is a closed-circuit continuous-flow wind tunnel with a 1.5 m diameter of the open test section, Fig. 1. The controlled range of freestream velocity is 15-40 m/s. The turbulence level of the flow in the test section is greater than 0.5 percent. The wind tunnel driving system consists of four-bladed fan powered by a 55 HP AC motor.

The T-3 Institute of Aviation low-speed wind tunnel is a closed-circuit continuous-flow wind tunnel with a 5 m diameter open test section and 6.5 m length, Fig. 2. The maximum air velocity in the wind tunnel test section is 90 m/s, which corresponds to Reynolds number per meter $Re = 6.2\cdot 10^6$. The flow in the test section is relatively uniform with a longitudinal turbulence level of about 0.5 percent. Test section airflow is produced by 7 m diameter 8-bladed fan powered by a 5.6 MW AC motor.

2.2. Tested model

To assess a reliability of the obtained wind tunnel tests results in a two- and three dimensional wind tunnel tests two models in two wind tunnel were tested. The objects of the study were the two-dimensional NACA 0012 airfoil model (Fig. 3 and 4) and three-dimensional Tu-154M aircraft model (Fig. 1 and 2).

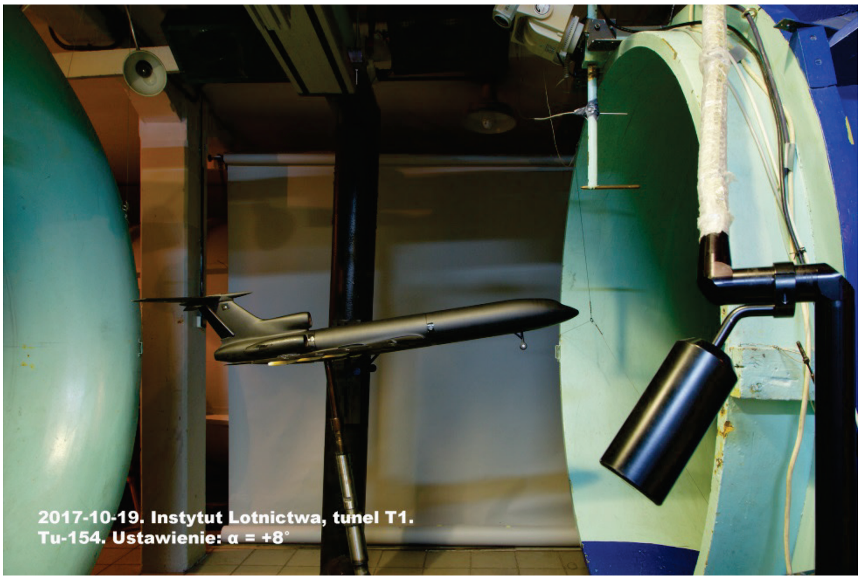

Fig. 1. Model of the Tu-154M aircraft in low speed wind tunnel T-1

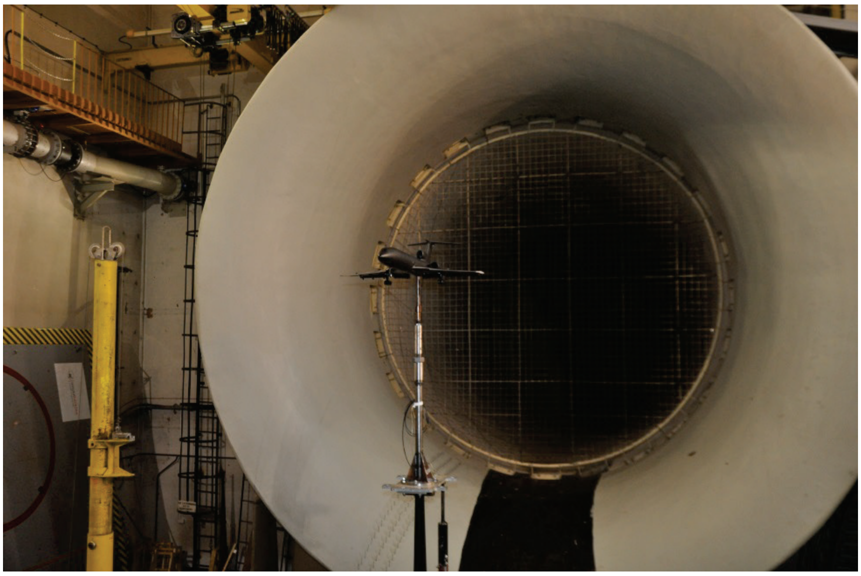

Fig. 2. Model of the Tu-154M aircraft in low speed wind tunnel T-3

The two-dimensional model of the NACA 0012 airfoil used in the experimental tests in the low-speed wind tunnels T-1 and T-3 had a chord of 0.5 m and a span of 1 m. It was a composite model. Aerodynamic characteristics of the NACA 0012 airfoil model were determined on base of pressure distribution measurements. To measure the pressure distribution along the model chord the 39 measurement orifices of 0.5 mm diameter were distributed on the model upper and down surface in the middle of its span. Behind the model, at a distance of 528 mm, the rake of stagnation and static pressure probes were placed to measure pressure distribution in the wake. All the measured pressures from the airfoil model, from the wake rake and pressure of undisturbed flow (total and static), were measured by electronic pressure scanners ESP-32HD (with a measuring range of ±10 inch H_2O, i.e. 2.491 kPa), as a part of data acquisition system "INITIUM".

The three-dimensional Tu-154M aircraft model was designed and manufactured by the Military University of Technology. It was a model of $b = 0.939$ m wingspan and $L = 1.197$ m length (on a 1:40 scale) manufactured fully in the rapid prototyping technology (Fig. 1). The aerodynamic characteristics of the tested Tu-154M aircraft model were measured by the 6-component internal balance Rollab I-646-2.

Fig. 3. Model of the NACA 0012 airfoil in low speed wind tunnel T-1

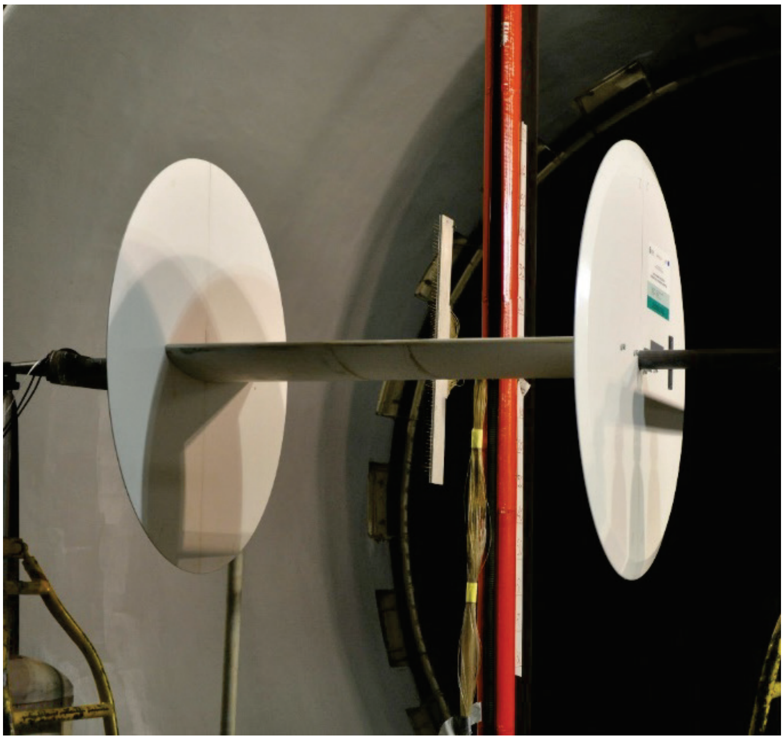

Fig. 4. Model of the of the NACA 0012 airfoil in low speed wind tunnel T-3

3. Wind tunnel tests results

Described in the article wind tunnel tests of the two-dimensional NACA 0012 airfoil model and three-dimensional Tu-154M aircraft model were carried out at undisturbed flow velocity V = 40 m/s what relate to the Reynolds numbers, $Re = 1.35 \cdot 10^6$ for the airfoil model and $Re = 0.35 \cdot 10^6$ for the aircraft model. An analysis of correctness of the obtained test results were performed on base of lift coefficient.

In Fig. 5 a comparison of the lift coefficient (C_L) versus the angle of attack characteristic for the same model of NACA 0012 airfoil obtained from the two low speed wind tunnels T-1 and T-3 without using wind tunnel corrections is presented.

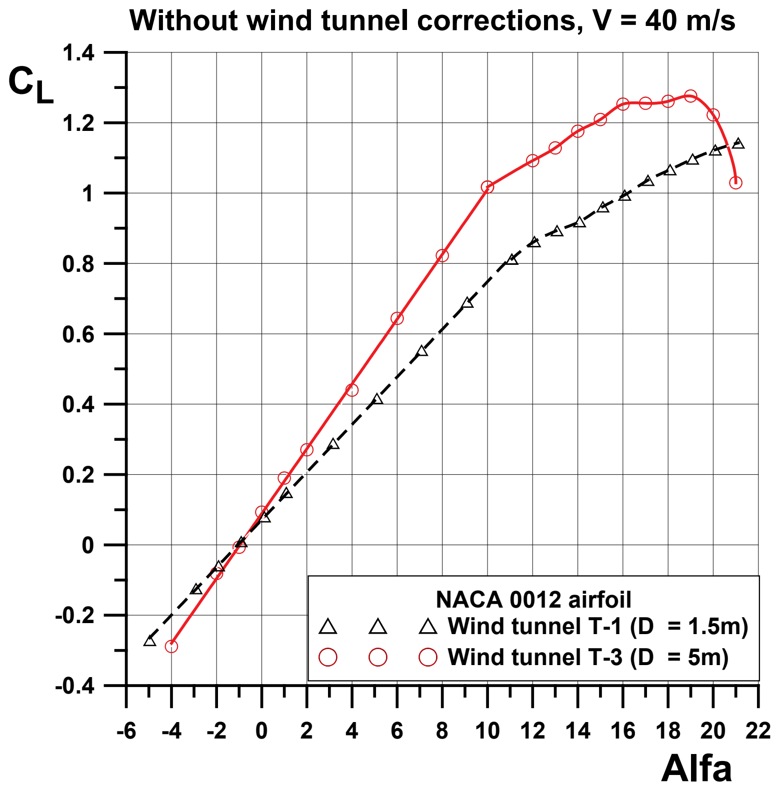

Fig. 5. Comparison of the $C_L = f(\alpha)$ characteristic for the NACA 0012 airfoil obtained in the low speed wind tunnels T-1 and T-3 without wind tunnel corrections

A comparison of the $C_L = f(\alpha)$ characteristics obtained in two wind tunnels (presented in Fig. 5) showed an essential difference in the value of lift coefficient. The lift of the NACA 0012 airfoil model obtained in T-1 wind tunnel is considerably smaller than obtained in T-3 wind tunnel. Generally, it can be seen that the difference in lift coefficient increases with the angle of attack rise from $\Delta C_L = 0$ for $\alpha = 0^o$ up to $\Delta C_L \sim 0.24$ for $\alpha > 10^o$. A decrease in the value of the airfoil model lift in the low speed wind tunnel T-1 (in comparison with wind tunnel T-3) is caused by a relatively large of the airfoil model chord dimension (c = 0.5 m) in comparison with the diameter of the wind tunnel T-1 test section (D = 1.5 m). At the angle of attack $\alpha = 10^o$ the airfoil model covered about 5% of the wind tunnel cross section. In such a situation, airfoil model causes a significant change in the air stream direction diminishing the effective model angle of attack and in consequence diminishing the model lift. In the case of wind tunnel test of the NACA 0012 airfoil model in the wind tunnel T-3, where the test section is large (D = 5 m) in comparison with the model chord (at the angle of attack $\alpha = 10^o$ airfoil model covered about 0.4% of the wind tunnel cross section), the changes in the air stream direction caused by the model are not so important.

In the case of wind tunnel test of the NACA 0012 airfoil model in the wind tunnel T-3 to the obtained reliable test results, it is necessary to introduce wind tunnel corrections. A comparison of the lift coefficient (C_L) versus angle of attack for the model of NACA 0012 airfoil obtained in the two low speed wind tunnels T-1 and T-3 with using wind tunnel corrections (for both wind tunnel tests) is presented in Fig. 6. The corrections are introduced in accordance with the recommendations. They included in the literature [2] and referred to the two-dimensional incompressible unseparated flow.

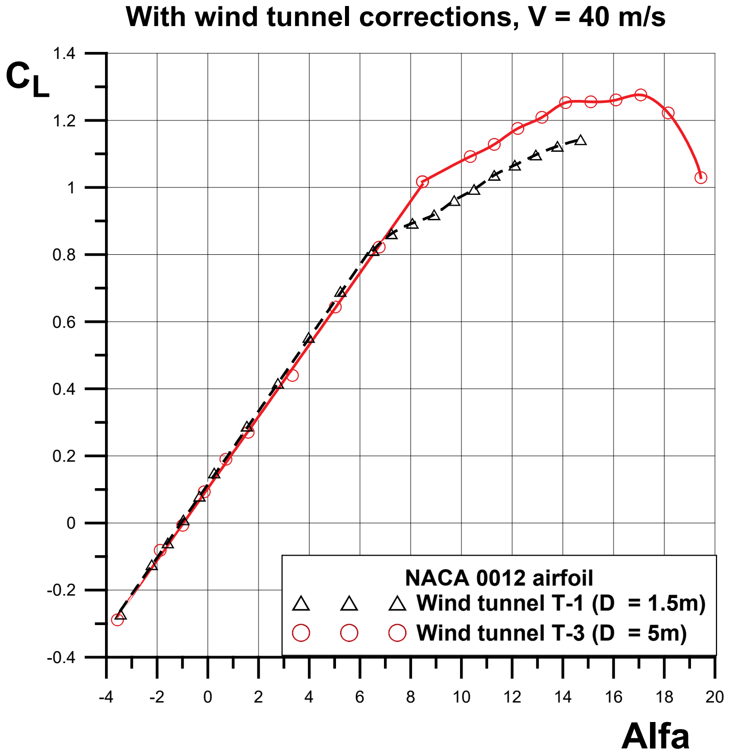

Fig. 6. Comparison of the CL = f(α) characteristic for the NACA 0012 airfoil obtained in the low speed wind tunnels T-1 and T-3 with wind tunnel corrections

After introducing the wind tunnel corrections the $C_L = f(\alpha)$ characteristic for the NACA 0012 airfoil obtained in two low speed wind tunnels T-1 and T-3 are compatible with each other in the range of angles of attack with the unseparated flow. The maximum lift coefficient obtained in the wind tunnel T-3 is about $\Delta C_L = 0.1$ greater than the one obtained in the wind tunnel T-1. There is no information in the literature about wind tunnel corrections in conditions of separated flow.

As regards to the correctness of the three-dimensional wind tunnel measurements a comparison of the lift coefficient (C_L) versus angle of attack characteristic for the same model of Tu-154M aircraft obtained from two low speed wind tunnels T-1 and T-3 without using wind tunnel corrections is presented in Fig. 7.

Without introducing any wind tunnel corrections the $C_L = f(\alpha)$ characteristic for the Tu-154M aircraft model obtained in two low speed wind tunnels T-1 and T-3 are generally compatible with each other in the range of angles of attack with the unseparated flow. On that ground, it can be concluded that the scale of the aircraft model has been chosen correctly and the model does not cause significant changes in the undisturbed flow direction. For the chosen model scale 1:40 at the angle of attack $\alpha = 10^0$ aircraft model covered about 1.5% of the wind tunnel T-1 cross section and 0.13% of the wind tunnel T-3 cross section. In both cases, no wind tunnel corrections are necessary.

The maximum lift coefficient obtained in the wind tunnel T-3 is about $\Delta C_L = 0.1$ greater than the one obtained in the wind tunnel T-1.

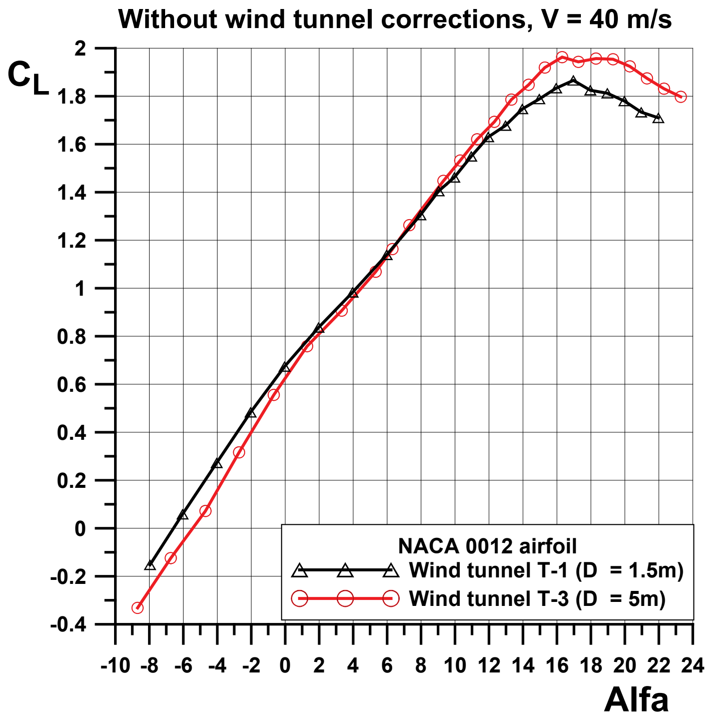

Fig. 7. Comparison of the CL = f(α) characteristic for the model of Tu-154M aircraft obtained in the low speed wind tunnels T-1 and T-3 without wind tunnel corrections

4. Conclusions

The two-dimensional airfoil studies and three-dimensional aircraft model balance investigation were performed in two low speed wind tunnels of different sizes of their test section. The main object of this study was to assess the correctness of the study on an example of the lift coefficient measurements. The wind tunnel tests were performed in two Institute of Aviation low speed wind tunnels, namely in the wind tunnel T-1 (of the 1.5 m diameter test section) and in the wind tunnel T-3 (of the 5 m diameter test section), at the same undisturbed velocity, $V_\infty = 40$ m/s.

The comparison of the lift coefficient characteristics obtained in two different wind tunnels using the same two and three-dimensional models and the same measurement technique enabled to discuss the problem of necessity of the wind tunnel corrections usage.

The research has led to the following conclusions:

- To ensure the reliability of the wind tunnel tests results, both in the two and three-dimensional studies the proper test preparation is necessary. One of the essential factors of this preparation is to determine the right proportions between the model size and the dimensions of the wind tunnel test section. On the one hand, the model should be as large as possible to reach high value of the Reynold's number (as close as possible to real conditions) and on the other hand it should not be too large so as not to cause a change in the direction of the wind tunnel undisturbed flow;
- The wind tunnel test showed that the two-dimensional airfoil model equipped with endplates significantly change the direction of the wind tunnel undisturbed flow. In that case the usage of wind tunnel corrections of the test data (correction of the angle of attack) is necessary;
- In the case of the three-dimensional balance measurements, when the area of the model cross section does not exceed 2-3% of the wind tunnel test section area, the usage of the wind tunnel corrections is not necessary;
- The differences in the value of the C_{Lmax} obtained in the described two- and three- dimensional measurements are most likely caused by the difference in the wind tunnels (T-1 and T-3) level of turbulence.

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