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ERRORS AND PROBLEMS WHILE CONDUCTING RESEARCH STUDIES IN A WIND TUNNEL – SELECTED EXAMPLES

Robert Placek

Institute of Aviation, Aerodynamic Department, Al. Krakowska 110/114, Warsaw, Poland
robert.placek@ilot.edu.pl

Abstract

This paper contains selected examples of errors and problems which can occur while conducting research in a wind tunnel. An inspiration to write this article was struggling with various problems during research experienced by the time period of working in aerodynamic tunnels of the Institute of Aviation . The bulleted list of examples refers to chosen types of research. Every mentioned kind of test is characterised by certain features and an individual approach. The work and methodology problems were the subject of interest. The content, however, does not exhaust the topic, but only reveals some of its aspects. In addition to a short description of selected topics, some actions were indicated ,which may help in future research. These suggestions might be useful, especially for novice researchers.
Keywords: conducting wind tunnel tests, problems in experiment, aerodynamic characteristics, wind tunnel corrections.

INTRODUCTION

Simultaneously, when first aerodynamic wind tunnels appeared, related research problems arose. The simulation of tested phenomena should be performed in accordance with so-called "good practice", which allows for more reliable imitation of real conditions. Therefore, the research conduction, where the use of the dedicated test equipment is required, should be performed by experienced personnel with specified knowledge in the area of the kind of the test. This is because each research method has its own features with some restrictions. A number of wind tunnel testing methods has already been described. The essential information-has been mentioned in literature (i.e. [1][2]), which is crucial during wind tunnel research. Because the wind tunnel application is more common in recent years (many wind tunnels were described in [3]), it should be kept in mind that their usefulness is determined by a proper usage. Although wind tunnel tests are performed, some essential factors which have an influence on the results are still not taken into account.

In this paper chosen examples are described, in which different impacts on wind tunnel results take place. It turns out that many underestimations are sometimes important. Besides, it also describes advise which can help to eliminate some of the components error in wind tunnel measurements.
Topics presented in this paper do not deplete the available range of knowledge, but only suggest

relevant issues according to the author. Therefore, topics should be complemented by reaching out for relevant literature.

2. GENERAL PRINCIPLES & HELPFUL TIPS DURING WIND TUNNEL TEST

Conducting a research in an aerodynamic wind tunnel concerns many detailed things which should be taken into account like, for example, various model preparation analysis [4], checks before/after wind tunnel run, wind tunnel run instructions and after test analysis. Because of such a big amount of information, every laboratory usually has its own regulations and policies. But sometimes, in spite of having instructions and trained staff, it is not easy to have a clear view at every stage of the whole testing process. Such a situation might result in the lack of some important information about test data, swapping tested data with others or drawing wrong conclusions.

The Institute of Aviation in Warsaw has its own wind tunnel test policy and regulations. Almost all requirements and test activities are described in specified instructions. Basing on the wind tunnel practise with its use and focusing on test conduction in the wind tunnel, the author pointed out some basic, non-written actions below:

- Check everything twice or find a person to do that (if possible),
- If something is unclear, check it or ask the right person,
- It is good to have 1-2 days to perform a pre-test with model use, where model functionality and propriety of measurement equipment will be examined,
- Make notes/hand drawings about every test details and notice every change that appears,
- Collect hand notes and put in a known, specified place,
- It is good to have many photos with details of the tested model and test measurement instrumentation,
- Make sure that orientation of the accepted model coordinate system is correct,
- Always begin wind tunnel tests at low speed values and low lift loaded model configurations. If test conditions are likely to destruct model or measurement equipment, the test personnel probably will be able to notice that first,
- If some tests go wrong, abort them. It can save the model from destruction,
- If some test results are different from typical ones, try to find an explanation or repeat the test to have results confirmation (if possible).

Tips mentioned above will be very helpful, especially during a preparation of a report from a performed test. The test cases from test matrix could be then described in more detail.

3. THE MODEL PITCH ANGLE ESTIMATION DURING WIND TUNNEL TEST

Before 2D airfoil or 3D model wind tunnel tests related with aerodynamic coefficients (of drag, lift or pitch moment) an estimation will be performed (balance or pressure tests). The tested object position in the wind tunnel test section should be defined first. It is a mistake to present the results directly as a function of the mechanical angle of the model.

The test object mounting activity in the wind tunnel test section is connected with a few stages which aim to ensure the most accurate model positioning.

For 3D model, the convergence of the model inclination angle should be checked first (or angle of model support mechanism) with a real, measured by calibrated spirit level device (or another calibrated device which measures angles). The model inclination accuracy should be possibly high. The literature indicates a deviation example equal ±0.01° for a balance test, which ensures repeatability of tests [5]. In practice, it is difficult to maintain such value and usually a little greater tolerance is taken (i.e. ±0.05°).

Additionally, when performing a balance test, the angle between the balance and the model should be checked. The wind tunnel practice, which the author has experienced, revealed that some models after manufacturing were not coaxial with the balance. The measured concentricity deviation angle value should be taken into account when changing from balance to model coordinate system (fig.1, α_b) [6].

Besides, in a tested angle range the set and the measured angle convergence should be checked. It would be ideally to have 100% compatibility, but usually it is not possible due to the model angle change mechanism accuracy. The suggested maximum angle deviation value in a testing range, which the author has observed, between the set and the measured angle should not be larger than (0.1°) [7].

Another factor, which has an influence on a proper angle of attack estimation (in the case of sting mounted model) is the sting deflection angle. Measurement checks should be performed on the final testing stand in the wind tunnel. The Sting deflection value is usually proportional to loads and can be estimated as follows (1) [8]:

$$\alpha_d = \alpha_N * N + \alpha_M * M \qquad (1)$$

where: α_N, α_M – elastic derivatives of pitch angle
N, M – normal force and pitch moment

One of the information which should not be omitted is the pitch flow angle. Its value should be known as its value is usually estimated during a wind tunnel calibration process. Otherwise, an estimation of its value can be done by performing initial wind tunnel tests with a model mounted in a normal and up-side down position. On the lift versus angle plot curves for both cases should be crossed on "0" value vertical axis. If it is not, the angle of flow correction value is given as the difference. It is worth remembering that it is important to apply this angle correction to a proper sign.

Another angle correction is related to the wind tunnel geometry and the model performance. Correction equations given in literature are strictly dedicated to a specified wind tunnel types and model types [1][9][10]. Proper corrections are usually set during a wind tunnel calibration process.

Taking into account all the mentioned angle corrections, it can be assumed that the real angle of attack is given as a sum of the following components (2) (fig. 1):

$$\alpha = \alpha_m + \alpha_d + \alpha_{flow} + \alpha_{WTcorr} \qquad (2)$$

where:
α_m angle of the model inclination
α_d angle of the sting deflection
α_b angle between balance and model
α_{flow} angle of flow pattern
α_{WTcorr} angle of wind tunnel flow correction

Presented corrections refer only to pitch angle. During tests with a 3D model the use of the yaw and roll angle corrections should be also taken into account. Although each presented pitch angle component value is usually small, the sum of them could be significant, especially for high force loaded models at a high angle of incidence.

During wind tunnel studies, where is the need to measure small increments in model loads, even better pitch angle accuracy is required. The error in the measurement of the pitch angle must then not exceed 0.01°. By the use of, for example, an accelerometer sensor the model angle precision can be increased [11].

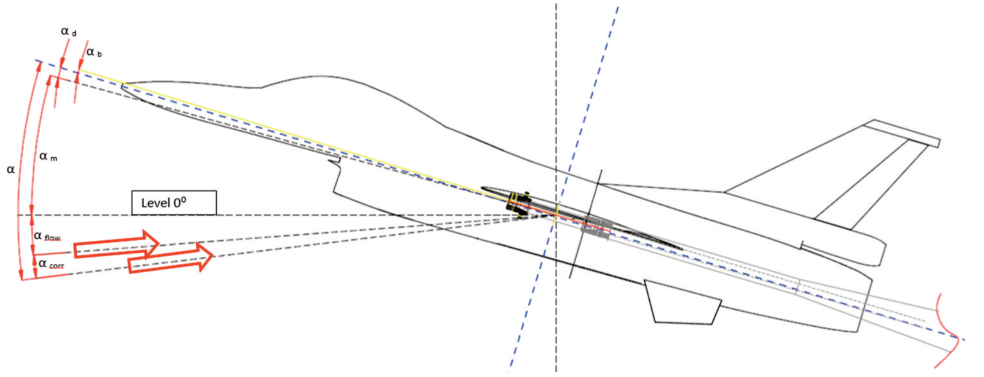

Fig. 1. The model angle of attack during wind tunnel test.,[own elaboration].

4. THE WAY OF THE MODEL ANGLE CHANGE AND ITS INFLUENCE ON TEST RESULTS

During various test performed in the wind tunnels of the Institute of Aviation, it has been examined that the way of the model angle change in the test could have an influence on the results.

In most cases it is related to the angle of incidence change mechanism hysteresis envelope. To avoid this problem, the same angle of incidence change manner should be applied for all tested cases, i.e. from lower to higher incidence values.

Yet, another situation is related to the initial model position in the wind tunnel test section. This could have an influence on the flow pattern development phenomena for the same model.
On one hand, the laminar boundary layer could separate from the model surface at the high angle of incidence, when gradually increasing incidence. On the other hand, accelerating flow meeting high inclined model at one tubulise the boundary layer and the flow separation tends to occur a bit later. To avoid such situations, the model position should be changed in the same way and from the same "base" model position.

The critical comparison example of lift and drag value for the same model at different wind tunnel run is shown in figure 2. The presented results differ due to different initial model inclination at the beginning of the run and the range of tested angles (Reynolds number was equal about 2.85 mln and Mach number M≈0.7).

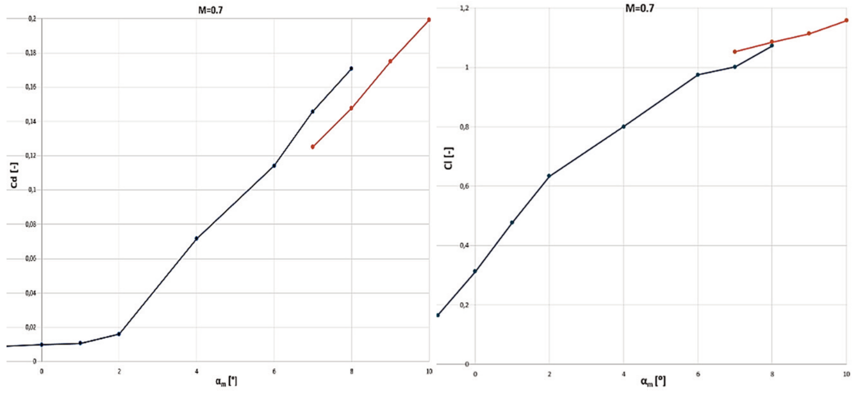

Fig. 2. The laminar airfoil aerodynamic coefficient comparison in terms of different initial angle of incidence set**.,[own elaboration].

5. THE WIND TUNNEL WALLS INFLUENCE ON THE TEST RESULTS

There are many examples of the wind tunnel walls influence on the results and dedicated corrections in literature, [1] [9] [10]. The wall influence on aerodynamic coefficients could be quite well estimated during the wind tunnel calibration process by applying proper corrections. They depend on the wind tunnel, wall type and are more significant at higher angles of attack.

In the Institute of Aviation wind tunnel wall corrections are also applied. The example of its influence on the lift coefficient for NACA0012 airfoil is presented in figure 3 [12].

Model limitations should be also taken into account. In general, the maximum size, angle of attack and model Mach number range are determined by a wind tunnel test section size and its design. In literature, in order to minimise wall effects, reasonable parameters values are indicated, i.e. value of the model chord to the test section height ratio (*c/h*). For example, due to the significant wall effect influence, for wind tunnels with closed test sections parameter *c/h* should be not greater than 0.4 for two dimensional wings. Additionally, due to blockage phenomena, the maximum ratio of the model frontal area to test section cross-area should be less than 7.5% [1].

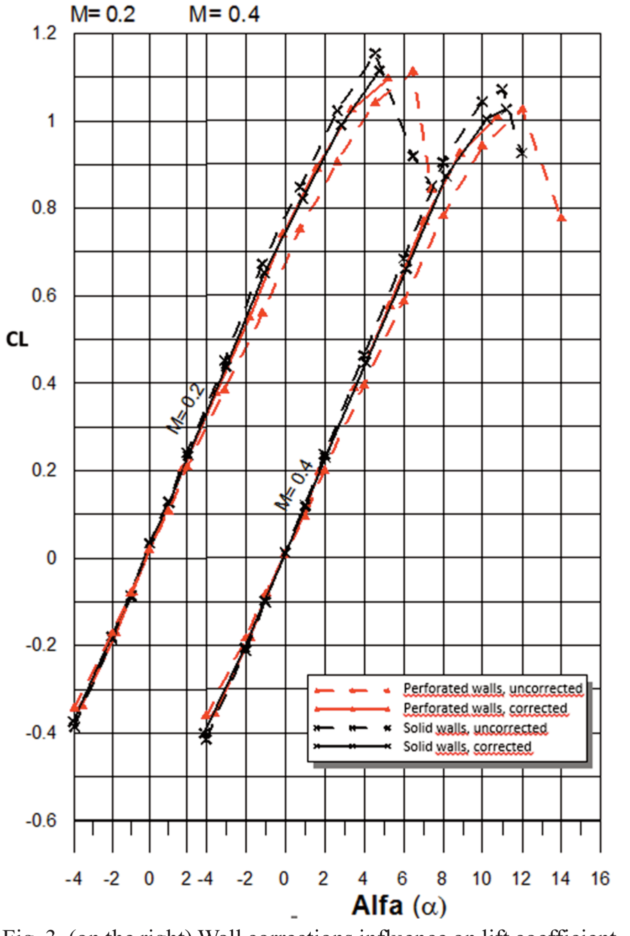

Fig. 3. (on the right) Wall corrections influence on lift coefficient values for NACA0012 airfoil in the IoA N-3 Wind Tunnel [12] */**

In the IoA N-3 high speed wind tunnel tested 2D airfoil models usually have the chord of 1/3 of tunnel height and frontal to wind tunnel cross section ratio less than 7% [13].

Applied principles in the laboratory are consistent with literature. At this point it is worth focusing additionally on the wall soured perturbations on the model surface. The presented example from oil visualisation test shows the wall corner influence on the laminar boundary layer region on upper model surface area (fig. 4). It is visible that for an airfoil model at a high incidence angle in transonic flow regime, the walls influence covers about 1/3 of its span. Placing measurement sensors (i.e., pressure type or hot film) in this area would be impropriate. When designing the arrangement of measurement sensors on the model surface, as one of the factors, the wall perturbations should be taken into account.

Fig. 4. The IoA N-3 Wind Tunnel wall influence on the laminar model upper surface area**, [own elaboration].

6. THE BASE AND CAVITY PRESSURE AS THE DRAG COEFFICIENT COMPONENT

When performing balance tests with sting mounted model in an aerodynamic wind tunnel, apart from sting deflection (described earlier), the support presence also should be taken into account. In general, independently of sting geometry, the string presence causes drag reduction [14]. As a result, the real drag of the body will be greater than measured by the strain gauge balance.
It can be assumed that the symmetrical model axial total force coefficient at zero angle of attack, measured by the balance will include the fore body, base and cavity pressure component (fig. 5) (3) [6] [15]:

$$CD_{TOTAL} = CD_{AF} + CD_{AB} + CD_{ACAV} \quad (3)$$

Then, it would be:

$$CD_{CORR} = CD_{TOTAL} + CD_{STING} \quad (4)$$

where:

CD_{TOTAL}	total model axial force coeff. (measured by balance)
CD_{AF}	fore body model axial force coeff.
CD_{AB}	base axial force coeff. (from base area)
CD_{ACAV}	cavity axial force coeff. (from cavity ring area)
CD_{STING}	cavity axial force coeff. (from sting area)

Although the above equation (4) allows for an estimation of the corrected drag of the sting mounted model in the wind tunnel, the sting interference has not been taken into account. In general, the sting presence changes also the value of the bottom pressure. It has a significant meaning for models with a relatively high base area, especially in subsonic and low supersonic speed ranges [16]. In order to estimate proper corrections, pressure measurements on the model base area should be performed with and without sting presence.

When performing balance tests, there is another experimental method allowing for estimation of the support interference. The method base on the combination of two different sting (method of doubling) [17] [18]. During investigation of the rear sting, model is mounted on another sing. Simultaneously, the rear sting is removed and afterwards simulated by a dummy sting. Experimental corrections are determined by comparison of aerodynamic coefficients for both model configurations. The correction of aerodynamic coefficient is estimated as below [17].

$$\Delta C(\alpha\infty, M\infty) = C_{DUMMY-} - C_{DUMMY+} \quad (5)$$

where:

C_{DUMMY-} coeff. without dummy sting
C_{DUMMY+} coeff. with dummy sting

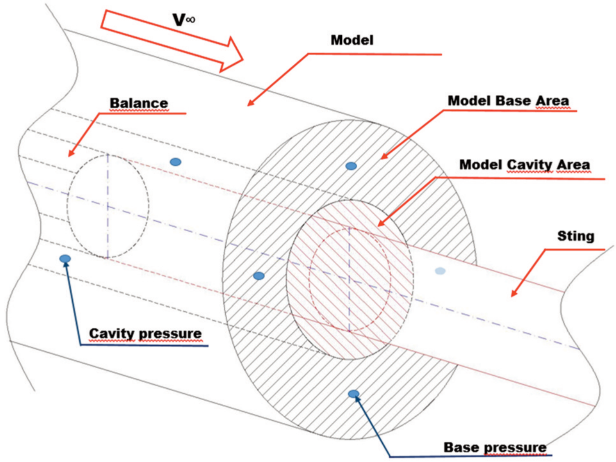

Fig. 5. The sting mounted model -Base and cavity area, pressure, [own elaboration].

7. THE TUFT FLOW VISUALISATION INFLUENCE ON THE TEST RESULTS

It has been examined that the tuft visualisation has an influence on the aerodynamic characteristics (fig. 6, on the left) [1]. The comparison example of lift coefficient value for the model with and without tufts glued on its surface is shown in figure 6, (on the right). The presented results differ, especially since the separation phenomena occurs (Reynolds number was equal about 1.5 mln and Mach number M≈0.11).

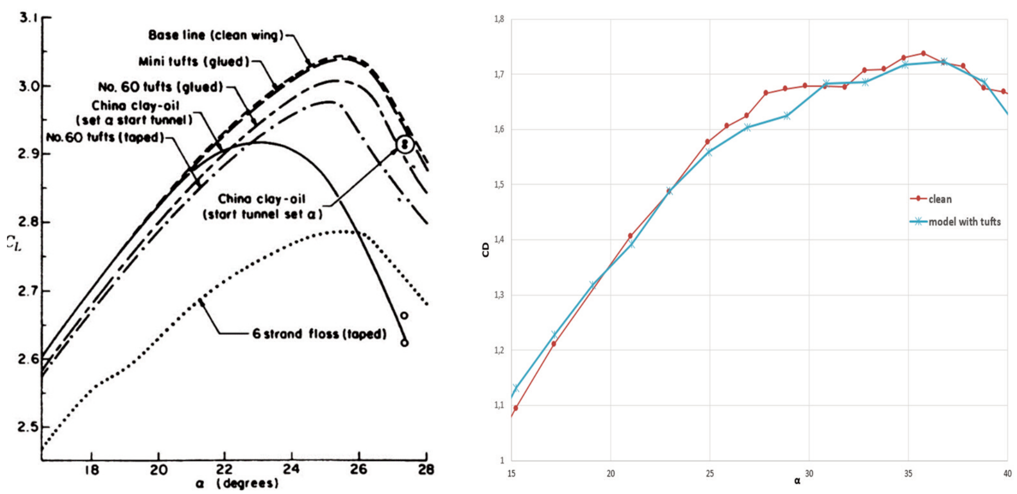

Fig. 6. The effect of oil/tuft visualisation on lift coefficient [1] (on the left), the high manoeuvrable fighter lift coefficient comparison of clean and tuft glued configuration (on the right), [own elaboration]*

The main reasons of changing aerodynamic performance, when applying the tuft visualisation method, is the earlier boundary layer transition and the increase of skin friction value on a visualized model surface. Because of the tuft influence on the model aerodynamic characteristic (especially when tufts are too big), the mentioned visualisation method should be treated as a qualitative source of information, which helps to understand the nature of flow near the model surface.

There is also a risk that the visualisation application may change the model surface quality. Because of that , the oil/visualisation methods should be performed as the last kind of test.

8. CONCLUSIONS

The wind tunnel research conduction is connected with many difficulties. The right way of performing tests makes wind tunnel research more complex and requires a proper approach to each kind of test separately. Errors occurring during a research usually take place due to the lack of some crucial information. Following rules of art treatment could be achieved more easily when the person conducting research has an adequate knowledge and experience about the test.

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BŁĘDY I PROBLEMY BADAWCZE PODCZAS PROWADZENIA BADAŃ W TUNELU AERODYNAMICZNYM – WYBRANE PRZYKŁADY

Streszczenie

Niniejsza praca zawiera wybrane przykłady błędów oraz problemy badawcze, z jakimi można się spotkać podczas prowadzenia badań w tunelu aerodynamicznym. Inspiracją do napisania niniejszego artykułu było borykanie się z trudnościami i problemami badawczymi w czasie zdobywania doświadczenia podczas wieloletniej pracy w tunelach aerodynamicznych Instytutu Lotnictwa. Wypunktowane w pracy przykłady odnoszą się do różnego rodzaju typu badań. Każde z wymienionych badań jest scharakteryzowane przez określone cechy oraz sposób indywidualnego podejścia. W pracy skupiono się na opisie problematyki prowadzenia oraz metodologii badań. Niniejsza praca nie wyczerpuje tematyki, a jedynie przedstawia jej wybrane aspekty. Oprócz opisania wybranych zagadnień, zasugerowano pewne działania, które mogą być pomocne w przyszłych badaniach. Wymienione wskazówki mogą być użyteczne, szczególnie dla początkujących badaczy.
Słowa kluczowe: prowadzenie badań tunelowych, problemy w eksperymencie, charakterystuki aerodynamiczne, poprawki tunelowe.