Lift measurement of airfoil AH93-157 from wall pressure distribution

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Abstract. Measurement of the lift coefficient of the AH93-157 airfoil was performed by measuring the static pressure distribution on the wind tunnel walls along the test-section. A correlation was established between the lift coefficient value, determined by integrating the static pressure distribution on the wind tunnel walls, and the lift coefficient value, determined by integrating the static pressure distribution on the airfoil surface. This method is useful for easy and quick determination of the lift coefficient on a simple airfoil model without complicated static pressure tubing from the surface. The measurement was made within a closed test-section. The correlation relationship also eliminates the problem of the finite span and the effect of the side walls. Comparison of pressure distribution on airfoil with CFD was performed as well.

1 Introduction and motivation

Unmanned flying devices, drones (UAVs) are currently experiencing a fast rise. In order to improve the performance of these advanced vehicles, the propulsion and aerodynamic design needs to be optimized. These vehicles exhibit (compared to conventional manned aircraft) significantly smaller dimensions and achievable wing and propeller speed. UAV-wings and propellers operate at significantly lower Reynolds numbers than manned aircrafts.

In the available literature, there is minimal information on the characteristics of airfoil at so-called low and very low Reynolds numbers. Thus, it is difficult to perform UAV parameter optimization when there are not enough good baseline characteristics of airfoil at low Reynolds numbers.

This paper focuses on simplifying the method of experimental investigation of the lift from the static pressure distribution on the walls of the wind tunnel measurement section.

2 Measurement of the lift from the static pressure distribution on the walls

2.1 Method of measurement of the lift coefficient

The method of experimental investigation of the lift (lift coefficient) of the wing model from the static pressure distribution on the walls of the wind tunnel test-section is based on the integration of the static pressure difference on the opposite walls of the experimental channel. The problem is considered as two-dimensional. The basic principle of "action and reaction" is used, whereby the gradient of the static pressure field induced by the wing model in the test-section is reflected in the pressure field on test-sections walls. Direct measurement of the static pressure distribution on the airfoil is difficult and requires a wing model equipped with pressure taps, which is quite expensive. It is therefore not possible to use this procedure routinely. Another possibility is aerodynamical ballance and direct measurement of forces. Using this static pressure based method, the static pressure gradients are measured on the walls of the test-section, which are opposite to the suction and pressure side of the wing model. The measurement of the static pressure distribution along the walls of the test-section is carried out directly by means of a series of separate pressure taps. The observed static pressure waveforms are integrated and their difference corresponds to the lift acting on the airfoil. Since the test-space, or the area where the static pressure is measured, is limited, the relationship between the actual lift coefficient and the coefficient found by integration must be calibrated. For calibration purposes, it is necessary to know the actual lift coefficient of the wing model. An aerodynamic weight can be used to determine this or, as in our case, the static pressure distribution on the suction and pressure side of the wing model can be measured, since a model of the wing section with airfoil AH93-157 with static taps was available. By integrating the static pressure distribution, the actual lift coefficient is obtained. The advantage of this method is that it is based on a direct measurement of the local pressure field generated by the airfoil in the test-section. Calibration of the test-section by the wing model with pressure taps largely eliminates the effect of the finite size of the wing model, the effect of the model endings is very well eliminated, and the measurement is not affected by the flow in the gap between the model sides and the walls or the forces acting on the end-plates or by side wall effecst, as is the case for lift coefficient measurements using aerodynamic ballance. Second advantage of this method is that after calibration of the test-section it is possible to use wing models without special modifications. The end-plates are replaced directly by the test-section walls. The disadvantage of this method is the need to measure (ideally simultaneously) a large number of low pressures. It requires high-quality

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equipment for measuerement of a larger set of low pressures. [1]

2.2 Experimental setup

The experiments were carried out in the closed type wind tunnel cross section of the test-section of the wind tunnel was 0.9 m x 0.5 m. [2] The length of the test-section was 0.8 m. The free stream turbulence intensity *Iu* (at the leading edge of the model level) was naturally *Iu* = 0.009. The side walls of the test-section were each fitted with 16 static pressure taps (diameter 5E-4 m). All were connected to a common pressure connector (64 pressures).

2.3 Model

It was tested the AH93-157 airfoil, (Fig. 1). [3-5] The length of the model wing chord was 0.4 m, the span of the model was 0.5 m. The model was fitted with 45 static pressure taps (diameter 5E-4 m) on the suction side and with 45 static pressure taps on the pressure side. The static pressure taps were routed through the model interior and through the wall to the outside of the test section and connected via two multichannel pressure connectors (64 pressures) to the pressure scanner. The model of the wing was placed in the test section in a vertical position and was and was pivotally placed between the upper and lower wall of the test-section, see Fig. 2 and Fig. 3.

2.4 Measurement aparatus

Static pressure readings were taken using an Esterline Pressure Systems ESP 64HD pressure scanner. The pressure scanner was housed in a tempered thermobox (43°C). The pressure scanner was equipped with a pressure connector for easy connection of static pressure taps leadings from the walls of the test-section and from the suction and pressure side of the wing model. Measurement was made by connecting individual sets of static pressure taps for each case in turn. Unloaded pressure scanner readings were taken as a reference of zero signal.

The output signals from the pressure scanner were read using PCIe 6251 measurement card, and data acquisition was performed using dedicated software in the LabView software. A calibration of the pressure scanner with 4th order correction was applied and performed in the appropriate range. (range 1 kPa, accuracy ±0.015 % FS).The flow velocity reference was measured as the static pressure difference on the inlet difusser (contraction nozzle). The pressure signal and barometric pressure were connected to a Druck DPI 145 pressure transducer (range 7 kPa accuracy ±0.005 % FS).

Flow temperature was measured with a Pt100 thermometer. The turbullence intensity of the flow in the inlet was mneasured using single hot wire probe and Dantec Streamline unit. The output voltage was sensed by the HP 34970A data acquisition unit. Data ordering and graphs was made using MS Excel.

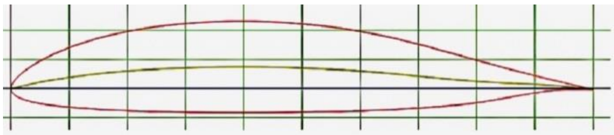

Fig. 1. Airfoil AH93-157 (http://airfoiltools.com/airfoil/details?airfoil=ah93157-il 10.11.2021).

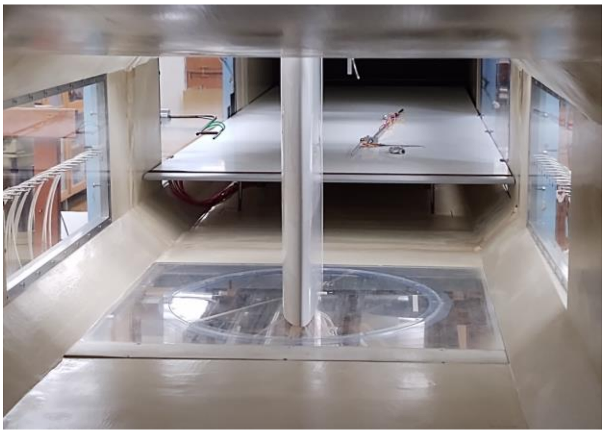

Fig. 2. Front view on the model (placed vertically) inside the test-section of the windtunnel.

Fig. 3. Side view on the model (placed vertically) inside the test-section of the windtunnel.

3 Results

3.1 Experimental results

The Fig. 4 and Fig. 5 show the static pressure distribution in dimensionless form of the local lift coefficient on the AH93-157 wing model and the static pressure distribution on the walls. On the Fig. 4 is evident different static pressure reference in comparison with CFD results.

The experiments were carried out by 14 m/s, corresponding *Re* = 4.1E5, turbulence intensity *Iu* in the inlet was measured *Iu* = 0.9 %. The static pressures were measured using pressure scanner, the time (duration) of data acquisition was t_a = 30 s.

3.2 CFD simulations

The experimental data were supported by numerical mathematical model. The *k-kl-omega* turbulence model was used, see example in the Figure 4 and Figure 5. The preliminary results was presented, simulation was performed for turbulence intensity *Iu* = 0.1 % and without test-sections walls modelling, so in the free stream. The simulation will be repeated for the case, where the walls are present in the future.

After sumarising of both parcial lift coefficients is evident, that the experiment is relatively in well agreement with CFS simulation. CFD simulation was made in the free flow field, so some correction of its results is necesarry.

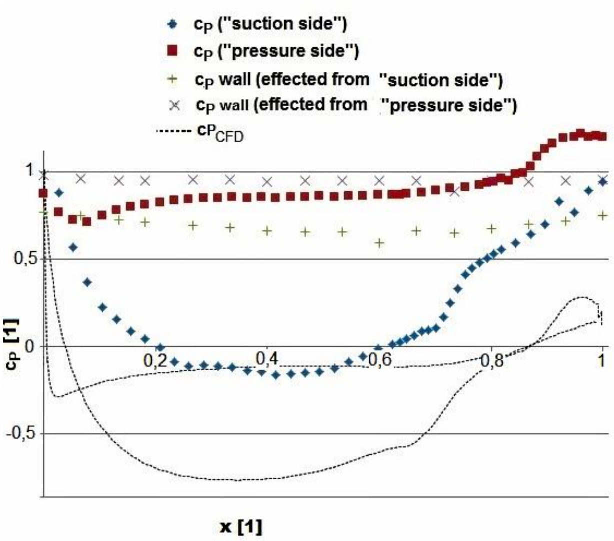

Fig. 4. Pressure coefficient c_P for suction side c_{PH} and pressure side c_{PD} of the airfoil AH93-157 and pressure coefficient c_{PW} on the corresponding walls. Experimental and preliminary CFD results, angle of attack α = 0 deg. The flow separation is good recognizable.

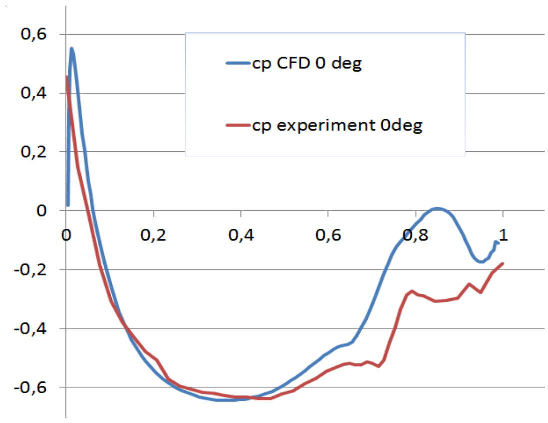

Fig. 5. Lift coefficient c_{PL} distribution along the chord of the AH93-157 airfoil.

3.3 Lift coefficient

It was possible to determine the lift coefficient for the AH93-157 airfoil by specified angle of attack α and Reynolds number *Re*.

$$c_{PL} = c_{PD} - c_{PH} \tag{1}$$

For example, for Reynolds number *Re* = 4.0E5 and angle of attack α = 0 deg, the lift coefficient was c_{PL} = 0.63. For presentet case (α = 0 deg) was detected the pressure difference on the walls of the test-section expressed by the pressure coefficient c_{PW} inducted by the model of the wing, corresponding pressure coefficient was c_{PW} = 0.27. The flow separation is very good recognizable, see Figure 4 and Figure 5.

3.4 Test-section calibration

Calibration of the test-section is presented in the Table 1 and Fig. 6. Calibration is expressed as the ratio of the lift coefficient and pressure wall coefficient c_{PL} / c_{PW}.

Table 1. Lift coefficient c_{PL} of the airfoil AH93-157 and pressure coefficient c_{PW} of the effected walls

α [°]	c_{PL} [1]	c_{PW} [1]	c_{PL} / c_{PW} [1]
-5	0.39	0.02	19.5
0	0.63	0,27	2.33
5	0.95	0.48	1.98
10	1.08	0.57	1.89
15	1.11	0.61	1.82
20	1.06	0.65	1.63
25	1.18	0.73	1.61

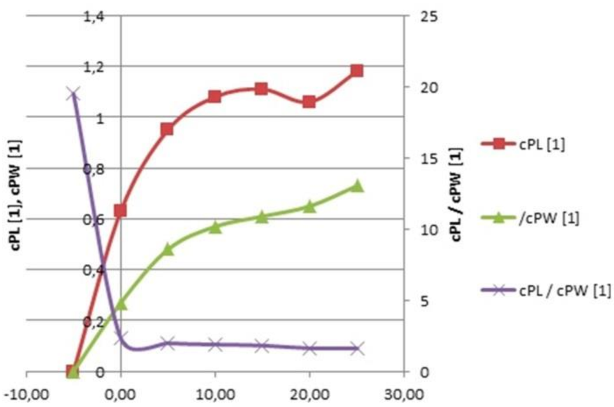

Fig. 6. Lift coefficient c_{PL} of the airfoil AH93-157 and pressure coefficient c_{PW} on the corresponding walls dependent on the angle of attack.

4 Conclusions

Experimental data on aerodynamic airfoil are rarely available for lower values of Reynolds number, examples can be found in [6-8].

At last a basic experimental determination of the most important characteristics of the airfoil can be performed using the procedure described above.

This method is capable to investigate large number of different airfoil variants, which can nowadays be easily realized by rapid prototyping (3D printing) methods. Other more experiments will be done in the next future.

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