# LOW-SPEED WIND TUNNEL TESTING FOR AN UNMANNED AERIAL VEHICLE AIRFOIL

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***Abstract:*** *This paper presents low speed wind tunnel tests of a 2D NACA airfoil which were performed by means of an aerodynamic measurement system. The lift, drag forces and pitching moment are shown. Finally, results of the wind tunnel tests were compared with references and found to be in good agreement.*

*Keywords: Aerodynamic balance, Wind tunnel test, Low Reynolds number, Unmanned aerial vehicle.*

## INTRODUCTION

Unmanned aerial vehicles commonly referred to as UAVs are defined as powered aerial vehicles sustained in flight by aerodynamic lift over most of their flight path and guided without an onboard crew. They may be expendable or recoverable and can fly autonomously or piloted remotely. UAVs are a key element within the concept of information dominance. In the Laboratory on Fluid Mechanics in the Czech Technical University in Prague, particularly in the branch of aerodynamics, an aerodynamic measurement system needs to be tested, this paper presents the low speed wind tunnel testing results of a 2D NACA 2415 airfoil, comparing it with results in [1] and [4], measuring lift, drag forces and pitching moment.

## MEASUREMENT SYSTEM APPARATUS

The measurement system includes three components, a low speed wind tunnel system, the aerodynamic balance and data processing software.

## WIND TUNNEL SYSTEM

The closed-circuit wind tunnel has an open test section of 750 x 550 mm cross section. It is assembled from straight parts of a closed-return passage with rectangular cross section, elbows with corner-vanes, a rectangular settling chamber, a nozzle and an open test section. The honeycomb and two screens are placed in a closed-return passage as shown in Fig. 1. The maximum air velocity of 17 m/s can be obtained in the test section. A 55 kW three-phase induction motor and a frequency changer are coupled with fan. The flow velocity was measured directly with an anemometer vane type shown in Fig 6.

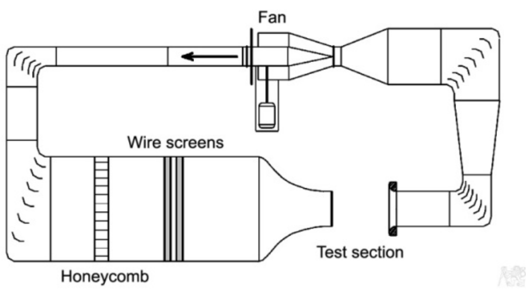


**Fig. 1. Low speed wind tunnel.**

## AERODYNAMIC BALANCE

The balance is composed of six high precision digital hanging scales with a capacity of 5kg and a resolution of 0,002kg located according to Fig. 2. Six forces are measured A, B, C, D, E and F. The wires A and B are parallel to the incoming velocity vector and define a place that can be taken as a reference plane for the balance (x-y plane), these wires point in the x direction. The wires attached to C and D are in a plane that is perpendicular to the x-y plane, which we designate the y–z plane. Wires A and C are attached to a common point on the left side of the wing. Wires B and D are attached to a common point on the right side of the wing. Finally wires E and F are parallel to C and D.

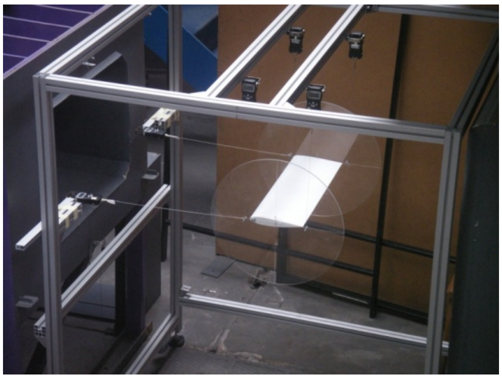

**Fig. 2. Location of scales in the aerodynamic balance**

**Fig. 3. Endplate detail**

The airfoil is attached to two endplates of transparent polyca ıese endplates have the main function of reducing considerably the the induced drag by blocking the leakage around the wing tips [2].

The balance can produce angle of attack changes from 0 to 16 lest increment of 2 degrees.

## DATA ACQUISITION AND PROCESSING

The procedure for the acquisition and processing the data is in agreement to the procedure for wire balances, attaching the model in an inverted position (upside down) so that aerodynamic lift added to the weight to prevent unloading the wires as the resulting tension can never be allowed to diminish to zero as reviewed in [2].

## CALIBRATION OF THE MEASUREMENT SYSTEM

Since the lift is the largest force by far in a typical aircraft complete model wind tunnel work, extreme care must be taken to ensure that it is orthogonal to the other components [2]. Therefore, the most precise perpendicularity between the wires had to be maintained; otherwise some component of the drag could appear improperly in the lift and vice versa.

## WIND TUNNEL TESTS

Low Reynolds number wind tunnel tests on a 2D-airfoil were performed, these results were compared to reference experimental data.

A NACA 2415 airfoil (Fig. 4), which has become increasingly popular on ¼ scale pylon racers [1], was tested as seen in Fig. 2. The airfoil had a chord length of 200 mm and a span of 600 mm, which means an aspect ratio of 3. The body of the model was made of expanded polystyrene foam (EPS) and coated with a layer of solid polystyrene as shown in Fig. 5.

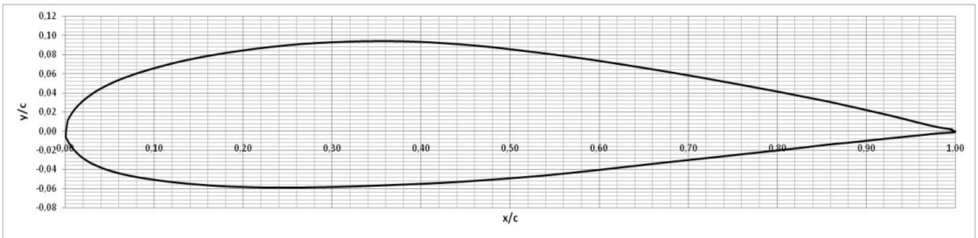


**Fig. 4. NACA 2415 airfoil**

**Fig. 5. Wing model**

In order to run the tests, the aerodynamic balance was fixed and aligned in the wind tunnel open test section, then the model previously attached to both endplates by means of screws and nuts was hanged in the four scales for lift which were attached to the balance structure and finally it was connected to the two drag scales forming an angle of 90 degrees. The wind tunnel tests were performed at a stream velocity of 8,7 m/s and a Reynolds number of 108000, the angle of attack was set from 0 to 16 degrees with an increment of 2 degrees. The experimental results were then compared to experimental data from references at Reynolds numbers of 100000 and $3x10^6$.

## RESULTS AND DISCUSSION

In the following graphs the performance of the model of a NACA 2415 airfoil is shown, experimental data from references at different Reynolds numbers [1,4] are also included.

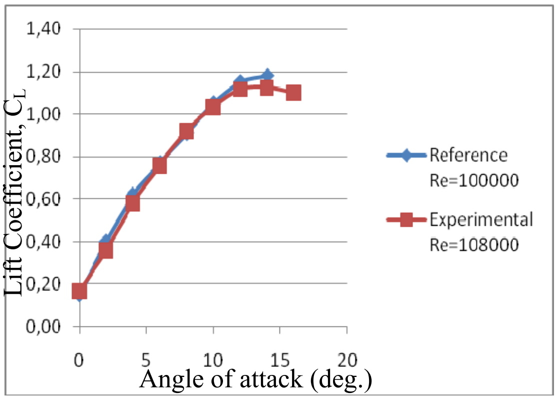


**Fig. 6. Lift coefficient graph of the NACA 2415 airfoil**

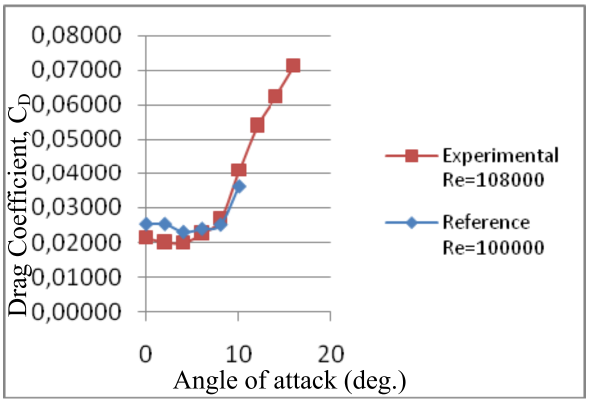


**Fig. 7. Drag coefficient graph of the NACA 2415 airfoil**

In the lift coefficient graph shown in Fig. 6, it can be observed that the stall region appears for an angle of attack of 14 degrees with a $C_L$ of approximately 1,13. In this point, the measured $C_L$ is lower that the $C_L$ from references. Both curves follow the same path and are in good agreement.

In the drag coefficient graph shown in Fig. 7, it can be seen that for small angles of attack, the measured drag coefficient is slightly smaller that the references, however, from 6 to 8 degrees, the measured and the reference $C_L$ are very similar and from an AOA greater than 10 degrees, the curves could not be compared because of a lack of information from references.

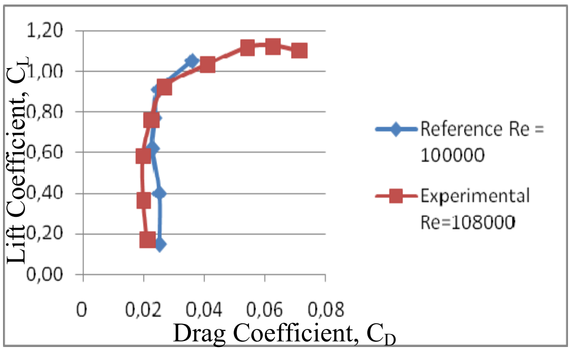


**Fig. 8. Drag polar of the NACA 2415 airfoil**

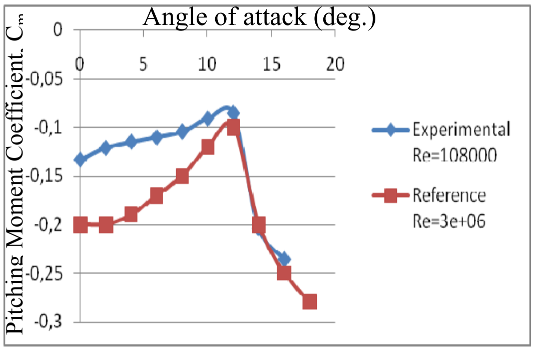


**Fig. 9. Pitching moment of the NACA 2415 airfoil**

The drag polar graph is shown in Fig. 8, it can be observed that both have similar behaviors. From an AOA greater than 10 degrees, the curves could not be compared because of a lack of information from references. This graph specifies the drag coefficient $C_D$ for a given lift coefficient $C_L$ and vice versa. This is often the most important part of the results and can be used to find the best climb or sink rate as well as the optimum glide angle ideally possible with this NACA 2415 airfoil.

In the pitching moment coefficient graph shown in Fig. 9, it can be seen that the coefficient from the reference [4] is higher than the measured one, however from an AOA of 12 degrees, the values are closer in between. Both curves follow the same slope. It is important to mention that due to lack of information for pitching moment coefficient at a Reynolds number of 100000 it was decided to use a reference at a Reynolds number of 3e+06 for comparing purposes.

## CONCLUSION

A wing model of a NACA 2415 airfoil was built and tested, the results were compared to reference data and found in good agreement. According to the results in this research, it can be concluded that the aerodynamic measurement system is acceptable for measuring the performance for different wing models for unmanned aerial vehicles.

## REFERENCES

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