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*Research Article*

# WIND TUNNEL RESEARCH ON THE INFLUENCE OF ACTIVE AIRFLOW ON THE LIFT FORCE GENERATED BY THE AIRFOIL

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**ABSTRACT**
The paper discusses the results of wind tunnel tests of airfoils with additional active airflow applied to their upper surfaces. These studies were carried out for a range of velocities up to 28 m/s in an open wind tunnel. Several types of airfoils selected for the examination feature different geometries and are widely applied in today's aviation industry. The changes in the lift and drag force generated by these airfoils were recorded during the study. The test bench for the tests was equipped with a compressor and a vacuum pump to enable airflow through some holes on the airfoil upper surface. A rapid prototyping method and a 3D printer based on a powder printing technique were applied to print the airfoils. All of their surfaces were subject to surface grinding to smooth their external surfaces. The wind tunnel tests with and without active airflow applied to airfoils are summarised in the paper.

**Keywords:** wind tunnel, airfoil, 3D printer.

## INTRODUCTION

Aerodynamic testing has been a primary method of assessment and verification of the aerodynamic models for many years. This is essential for modern aerospace, automotive and construction engineering as all kinds of objects such as aircraft and space vehicles or buildings and bridges can be tested in this way. A wind tunnel examination enables determining the aerodynamic forces acting on a given structure. Such knowledge is particularly useful for calculating the strength of structures especially during high-speed winds. The values of aerodynamic forces are also used to reduce the intensity of flow energy around objects, moving elements in particular by developing their geometry as close as possible to the ideal shape [1, 2]. Aerodynamic tests are carried out all over the world, particularly in research centres [3]. Also, Lublin University of Technology examines aerodynamic flow around a wind turbine and airfoils. The results presented in this paper were developed during the realization of the project funded by the Polish National Science Centre. The paper discusses the partial results of the related wind tunnel study done for airfoils with additional active airflow. The project's main assumptions, test preparation, bench design and test results are given in the further section in the paper.

## RESEARCH DESCIRPTION

The main objectives of the project was to determine the lift and drag forces of airfoils in terms of the application of active airflow to the airfoil upper surface and to increase the value of airfoil lift force, due to active airflow that occurs during laminar flow on the airfoil upper surface. This could change aerodynamic flow around the airfoil and pressure distribution, which could be reflected in a change of lift and drag forces generated by the airfoil. Figure 1 depicts the main objectives of the project.

As shown in the Figure 1, the research assumes airflow or suction to proceed from the airfoil top surface. Several types of airfoils are tested in terms of different values of wind velocities, angles of attack and arrangement of holes on the upper surface of the airfoil. The initial conditions of the research result from previous simulation studies in ANSYS Fluent.

## TEST BENCH

To satisfy the project purpose, a test bench with wind tunnel GUNT HM170 as its main element was constructed. However, this test bench needed to be modified and fitted with some necessary elements to study active airflow. Given the scope of the study, the necessary basic research conditions are as follows:

- registering the airfoil drag force,
- registering the airfoil lift force,
- changing smoothly the airfoil angle of attack,
- using several types of airfoils,
- delivering overpressure and vacuum to the airfoil,
- transiting smoothly from overpressure to vacuum,
- registering the velocity of airflow in the wind tunnel.
- registering the values of overpressure and vacuum,
- registering airflow temperature in the wind tunnel,
- exchanging quickly airfoils.

This bench requires additional systems to register certain parameters such as pressure, temperature, air velocity, etc. The ready bench is shown in Figure 2. The test bench consists of:

a) wind tunnel,
b) air pressure compressor,
c) vacuum pump,
d) air pipes,
e) temperature measurement system,
f) system for measuring overpressure and vacuum,
g) control system for overpressure and vacuum.

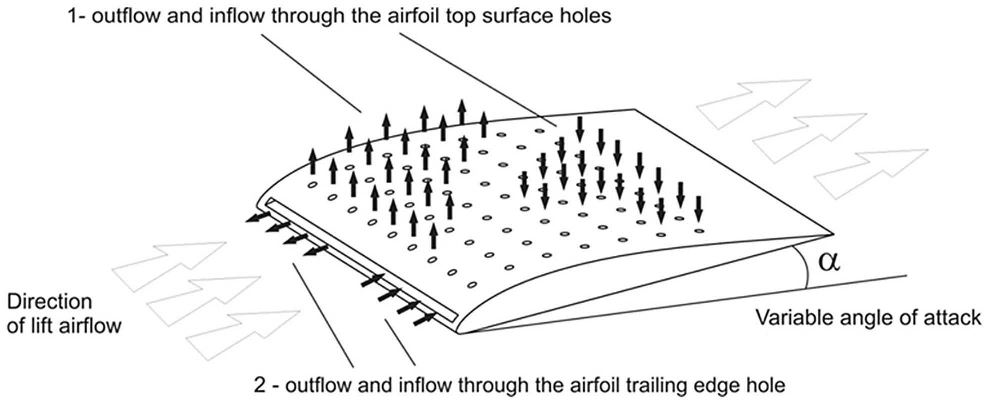


**Fig. 1.** Diagram illustrating the main objectives of the project

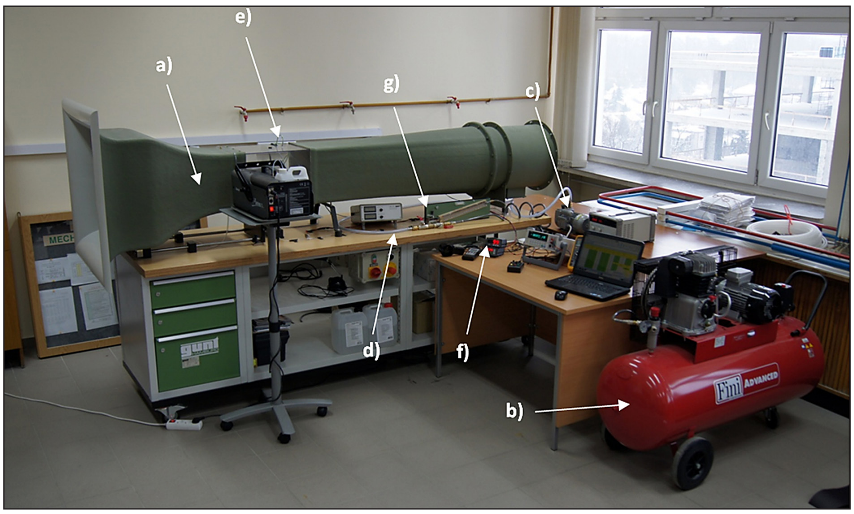


**Fig. 2.** Wind tunnel test bench for airfoils with active airflow

The test bench for airfoils with active airflow meets all of the relevant specifications. The high and low pressure system is capable of delivering compressed air into the airfoil. A correctly selected vacuum pump and air pressure compressor allows for smooth providing overpressure and vacuum for the on-going investigation. The temperature and pressure sensors satisfy the research measuring range. Another task related to the test bench involves the early adaptation of the workspace tunnel for test objects. The preparation of wind tunnel workspace is discussed in the next section.

## MODELS FOR THE WIND TUNNEL TESTING

The research project envisaged the use of rapid prototyping methods [4] to create geometric models for wind tunnel testing. The CAD airfoil geometry models were prepared given the method of mounting the airfoils in the wind tunnel workspace. The airfoils were designed using Catia v5 software, which is owned by the Department of Thermodynamics, Fluid Mechanics and Aviation Propulsion Systems. The process of designing was verified by 3D printing and simulation studies based on this geometry. The modelling and printing processes proved that some modifications are necessary to mount airfoils in the wind tunnel, and consequently, a new method of mounting based on two airfoil boundary surfaces was designed. These surfaces have two functions: airfoils are still mounted and the turbulence at the airfoil surface in the proximal part of the trailing edge is reduced. The lack of these surfaces, as it was demonstrated during the initial transient flow simulation, results in the turbulent flow on the airfoil surface, which affects the lift and drag forces. The design of airfoils focused on determining different shapes of these airfoils. Ultimately, the following types of airfoils were selected for the examination, given their variety and popularity:

- RAF 25,
- CLARK Y,
- DAVIS BASIC B-24,
- NACA 2415,
- NACA 63(2)-415,
- NACA 23015,
- NASA/LANGLEY/SOMERS NLF(1)-0215F.

However, to create real models, three-dimensional printer ZPrinter 450 was used. This printer is based on the so-called powder technique in which successive Z150 powder layers are cured by special binder ZB63 or ZB61. This printer and its main parameters are shown in Figure 3 and Table 1.

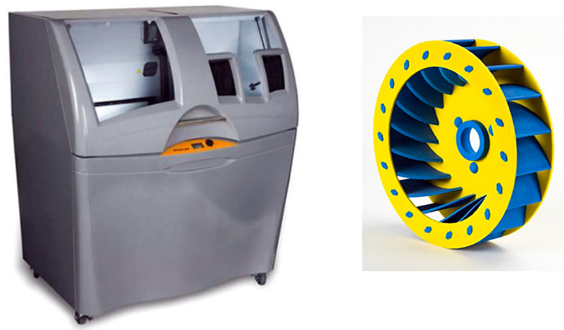

**Fig. 3.** ZPrinter 450 printer with a sample model

**Table 1.** ZPrinter 450 parameters

| | |
|---|---|
| Color | 180,000 colors (2 print heads) |
| Resolution | 300 x 450 dpi |
| Minimum Feature Size | 0.006 inches (0.15 mm) |
| Vertical Build Speed | 0.9 inch/hour (23 mm/hour) |
| Build Size | 8 x 10 x 8 inches (203 x 254 x 203 mm) |
| Material Options | High Performance Composite |
| Layer Thickness | 0.0035 - 0.004 inches (0.089 - 0.102 mm) |
| Number of Jets | 604 |
| File Formats for Printing | STL, VRML, PLY, 3DS, ZPR |
| Equipment Dimensions | 48 x 31 x 55 inches (122 x 79 x 140 cm) |
| Workstation Compatibility | Windows® 7, Windows® XP Professional and Windows Vista® Business/Ultimate |

Despite a high resolution 3D printer was applied, the procedure of grinding the airfoil outside surface, especially in the case of small geometric elements preceded the airfoil printing. This is particularly important in the study of aerodynamics because surface roughness is one of the factors that can significantly impact on the behaviour of air stream [5, 6]. Hand sanding with sandpaper of small roughness was applied to grind the airfoils.

The designed and printed airfoils as soon as the successful wind tunnel initial testing was accomplished were ready for the main tests. The ready airfoil that is mounted in the wind tunnel is shown in Figure 4.

The preparations for the construction of the test bench, design and development of the models for the wind tunnel testing were followed by the test of aerodynamic flow around the airfoils.

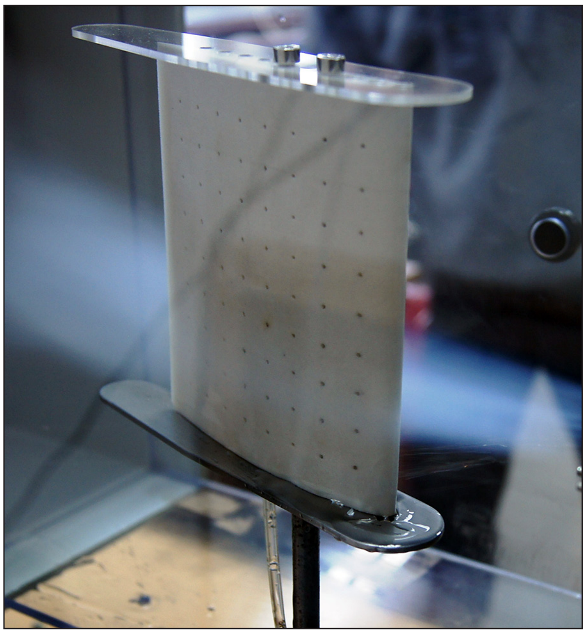

**Fig. 4.** Ready airfoil mounted in the wind tunnel

## RESEARCH

The first phase of the research includes the testing without active airflow generally to verify the simulation calculations. The second phase of the wind tunnel testing assumed to take full advantage of the bench testing of active airflow at different values of overpressure and vacuum. The number and arrangement of the holes on the airfoil upper surface were adopted on the basis of previous simulation studies. The impact of the inlet located on the leading edge of the profile was disregarded in the examination. Such a solution turned out to be pointless and affects the aerodynamics of the airfoils. The study was conducted for all of the previously mentioned airfoils. Boundary conditions for each of the airfoils were as follows: different values of angles of attack, wind velocity, and overpressure and vacuum.

Table 2 shows the values of the variables in the tests which were maintained for each test airfoil. In summary, the research was carried out for 750 cases of each airfoil.

## RESULTS

The paper discusses the results for one of the selected airfoils, i.e. Clarky. The results show the lift and drag forces with active airflow due to overpressure and vacuum: 0.5 kPa, 1 kPa, 2.5 kPa, 5 kPa, 7.5 kPa and 10 kPa at a 20 m/s airflow velocity and a 15° angle of attack.

The next stage of the study was to determine lift and drag coefficients. The values of the calculated coefficients are shown in Figures 7 and 8.

## CONCLUSIONS

The examination shows that the aerodynamic forces, i.e. lift and drag are hardly impacted by active airflow. Figures 5-6 show that vacuum can increase both lift and drag. The same graphs indicate that the lift and drag forces decrease with increasing overpressure. This fact can be proven by the values of the coefficients of these two forces given in Figures 7 and 8. Importantly, the most beneficial case would be to increase the lift force while reducing the aerodynamic drag force, if these solutions were applied in aviation. These results motivate to a more thorough examination of this phenomenon on the airfoil upper surface. Any further analysis should be carried out for a larger model and a wider range of airflow velocities.

### Acknowledgments

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**Table 2.** Research parameters

| Parameter name | Angle of attack [°] | Wind speed [m/s] | Overpressure [kPa] | Vacuum [kPa] |
|---|---|---|---|---|
| Parameter value | 0 | 12 | 0.5 | 0.5 |
| | 5 | 16 | 1.0 | 1.0 |
| | 10 | 20 | 2.5 | 2.5 |
| | 15 | 24 | 5.0 | 5.0 |
| | 20 | 28 | 7.5 | 7.5 |
| | 25 | – | – | – |

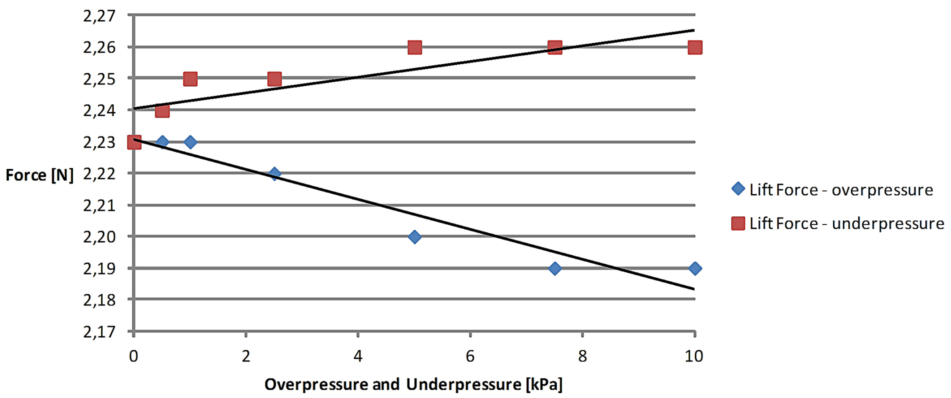


**Fig. 5.** Lift force for different values of overpressure and vacuum

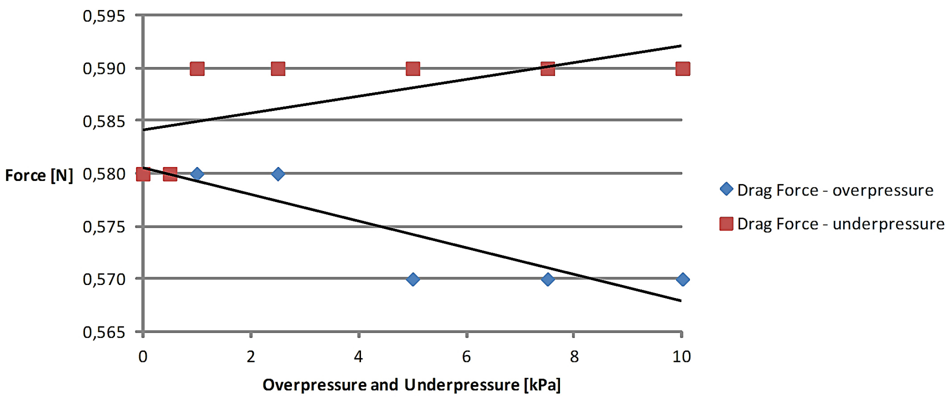


**Fig. 6.** Drag force for different values of overpressure and vacuum

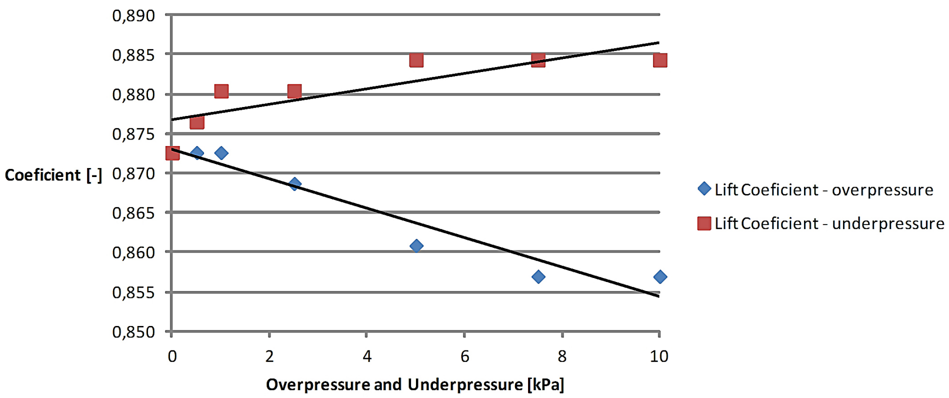


**Fig. 7.** Lift coefficient for different values of overpressure and vacuum

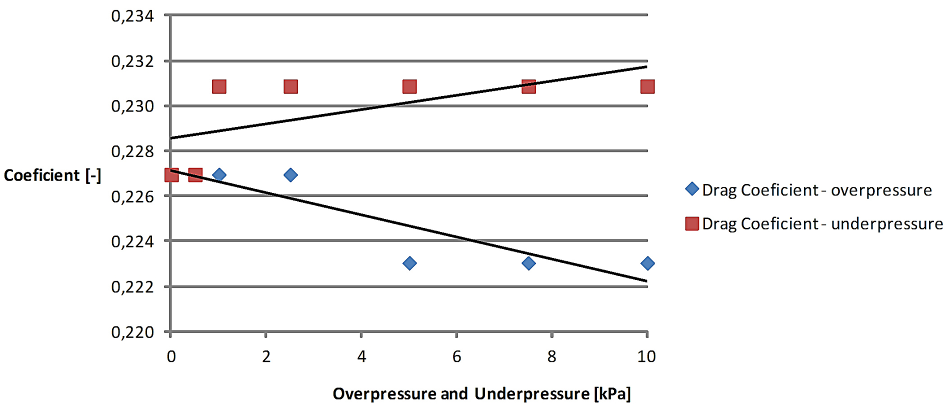


**Fig. 8.** Drag coefficient for different values of overpressure and vacuum

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