System for acquisition and processing of pressure data around body in airflow

D. Mežnarić, K. Krajček Nikolić, D. Franjković
Faculty of Transport and Traffic Sciences / Department of Aeronautics, Zagreb Hrvatska
domagoj.meznaric@gmail.com, kkrajcek@fpz.hr, dfranjkovic@fpz.hr

The article deals with the system and methods for determination of the pressure distribution around aerodynamically shaped body immersed in airflow and further calculations of aerodynamic characteristics. Measurements are conducted in the subsonic closed-loop wind tunnel AT-1, in Aerodynamics Laboratory of Department of Aeronautics at Faculty of Transport and Traffic Sciences. Pressure distribution around airfoil NACA 2421 is sensed by the system for acquisition of pressure data Intelligent Pressure Scanner 9016, produced by the Pressure Systems Company. Data are digitalized and transferred to the computer through the Ethernet link. Data are processed by NUSS and LabVIEW software. Measurement results are displayed and compared to those obtained from piezometric harp. Results of experiments are commented and recommendations for further research are given.

I. INTRODUCTION

Wind tunnels are devices or facilities for experimental measurements in aerodynamics and they are used from the early beginning of aviation. The tunnels are used to obtain high-quality experimental data, especially when certain data can’t be obtained by theoretical calculations. In the wind tunnel, a controlled flow of air is produced which is acting on the model - subject of research and physical quantities are felt and measured and physical phenomena arising from the interaction of the body and the air flow are observed and recorded.

The measurements were performed in the subsonic wind tunnel AT-1 on the model of wing made of airfoil NACA 2421. The aim of the experiment was the construction of the measuring system from the measuring model through the acquisition of pressure system to the computer with appropriate programs.

Intelligent pressure transducer of Pressure Systems company uses electrical resistance elements by which mechanical displacement caused by the pressure is converted into an electrical signal. It consists of two module of code 9016 each containing 16 measurement points, each with input for reference pressure which is equal to the atmospheric pressure of the ambient air. In addition to the two modules, there is pressure calibrator of code 9034. It is used to calibrate the measuring instrument to zero and for the range. The modules convert analog signal to digital and send it through the Ethernet connection to the computer where the signal is further processed.

The results are compared with the results of hydrostatic pressure measurements. Two softwares are used for data processing: NUSS and LabView. NUSS is a basic program used to calibrate and adjust the system, and LabView is used to obtain pressure distribution on the upper and lower wing surface and to calculate the lift and the drag force due to the pressure.

II. WIND TUNNELS

Wind tunnels are complex installations which in its test section simulate flow conditions similar to those around the actual object or model. Wind tunnels are divided in regard to the velocity in the test section (subsonic, transsonic, supersonic) and the shape of the airstream line (open- or closed-circuit). According to their purpose or operating mode, tunnels are divided into: tunnels with a controlled pressure, tunnels with variable density of the working fluid, tunnels for testing prototypes in full size, tunnels for flow visualization, tunnels for testing free flight (the model is not fixed on the sting), tunnels for testing of spiral maneuvers, testing the stability of the flight, testing icing conditions on aircraft or other vehicles, for testing V/STOL aircraft, for testing aerodynamic characteristics of cars and boats, as well as for other uses in civil engineering (wind load on the building), ecology (the spread of pollution by natural air flow, the boundary layer to the surface of the Earth), sports (car racing, sailing, ski jumping, cycling ...) and for many other purposes.

Wind tunnel AT-1 (Figure 1.) at the Faculty of Transport and Traffic Sciences is a closed-circuit tunnel with a single return line. The test section has elliptical cross-section and partly open. Other components of the wind tunnel are converging nozzle, corner sections with air routers, honeycomb and screens, diffuser, the electric motor and fan, and the return line. Scheme of the wind tunnel AT-1 is shown in Figure 2.

Figure 1. Wind tunnel AT-1
The test section is the most important part of the wind tunnel, the required form of flow is obtained there, model and measurement equipment is located inside and measurements carried out. Through convergent nozzle, air is accelerated to the required speed due to the narrowing of the cross section of nozzle. Honeycomb and screens have to give enough laminar flow.

Angle sections are fitted with blades for deflecting the air stream to minimize losses due to turbulence. The purpose of the diffuser is to decrease the flow velocity of the working fluid, and thus the minimize power losses which are proportional to the third power of the speed. The electric motor drives fan which causes the airflow. Electric motor’s rotation speed can be controlled and thus determines the flow velocity in the test section. Speeds attained in the test section of the tunnel AT-1 are up to 50 m/s and Reynolds numbers of flow up to $10^6$. [1]

III. BODY MODEL AND PRESSURE DISTRIBUTION

The aerodynamic wind tunnel AT-1 at the Faculty of Transport and Traffic Sciences in Zagreb uses a wing model with 29 pressure measurement points. A model of “infinite” wing with constant length of chord line of 150 mm and standard airfoil shape NACA 2421 is used in this experiment. A model of the wing located in the test section of the wind tunnel is shown on Figure 3.

Static pressure on the surface of airfoil is measured on measurement points allocated on upper and lower surface of the wing. Figure 4. shows 15 measurement points on the upper surface of an airfoil from leading to trailing edge. The rest of measurement points are set over the lower surface from trailing to leading edge. Measurement points on airfoil are holes of small diameter (1 mm) which are placed perpendicular to the contour of the airfoil surface. From that place canals are installed inside the wing which are connected to the plastic pneumatic hoses.

Pneumatic hoses are connected on a two pressure measuring devices. Each hose from one measuring point is divided into two hoses which are connected on both U-tube manometer and Intelligent Pressure Scanner.

U-tube manometer, also called piezometric harp, measures the pressure on the surface of the wing by a set of U-tube gauges. (Figure 5.). Piezometer harp consists of as many gauges as measuring points on the test model, plus one measuring tube for the determination of a reference pressure. All measuring tubes have one end connected to a common reference pressure (usually the pressure of the surrounding atmosphere). Reading height of fluid in the tubes is done using a measuring tape, which is set in the immediate vicinity of the tubes.

That is one of the oldest methods for normal pressure measurement from measuring point on the contour of the airfoil through pneumatic lines to the hydrostatic pressure gauge. Such a method of pressure reading is outdated and very time-consuming due to slow processing of each measurement point on the contour of the airfoil. Newer methods use electro-mechanical pressure transducers described in chapter IV of this article. These electromechanical transducers are integrated into digital systems for the acquisition of pressure around the airfoil. Intelligent Pressure Scanner uses silicon electro resistive pressure transmitter.

Pressure distribution around an airfoil at some angle of attack is shown on Figure 6. Pressure is expressed as relative to the pressure at infinity and drawn as a vertical length above each elementary surface of the airfoil. All peaks are connected and that represents the pressure distribution around the airfoil. If the difference $p - p_\infty$ has a positive value in the observed point, pressure forces acts towards aerofoil and arrow is directed towards airfoil.
That happened on the lower surface of airfoil where airflow is slower than in infinity. On the upper surface due to increased speed static pressure will decrease and will be lower than $p_\infty$. That difference $p - p_\infty$ has a negative value which creates a vacuum that pulls the airfoil up. So overpressure on the lower surface and vacuum on the upper surface are lifting the model of the wing. [2]

![Pressure distribution around an airfoil](image)

Figure 6. Pressure distribution around an airfoil

IV. INTELLIGENT PRESSURE SCANNER

The system for data acquisition is used to collect data from various sensors and to convert that data into digital numerical value used by the computer. It converts analog signals to digital. Programs for systems acquisitions are made in various programming languages and the program that is used here is LabVIEW.

Measurement begins with pressure sensing. Pressure gauges used by this system are electro resistive elements also called piezo-resistive pressure transmitters. These devices are measuring the elongation of piezo-resistive element which stretches under the influence of the diaphragm (Figure 7.). If the thin electro-resistive element is loaded by force attributable to the action of pressure, it causes a change in the geometry of electrical conductor and therefore the electrical resistance of the wire.

![Piezo-resistive element](image)

Figure 7. Piezo-resistive element

Bending (tension and compression) of piezo-element generates very small changes in resistance. Deformation and fracture of strips are the limit for greater elongation. Therefore, extremely small changes in resistance have to be measured with great accuracy. Such a need for precision resistance measurement requires bridge circuit, a Wheatstone bridge. [3]

The Model 9016 Pneumatic Intelligent Pressure Scanner is a pressure acquisition module for multiple measurements of dry, non-corrosive gases. The scanner integrates 16 silicon piezo-resistive pressure sensors of large pressure range. This scanner has scanning speed up to 100 measurements per second on a single measurement channel. Each has its own reference pressure input, in this case atmospheric. Each pressure sensor is individually separated and incorporates a temperature sensor and EEPROM memory which stores complete information on digital temperature compensation. Housing incorporates also calibration valve, 16 bit A/D converter and 32 bit processor (Figure 8.). [4]

![Piezometer harpasad](image)

Figure 8. Piezometer harpasad

Scanner modules are connected with the computer via power supply unit and Ethernet interface (Figure 9). The computer communicates with measuring modules using 10 MBit TCP/IP and UDP/IP protocols. Each measuring module and the computer have a unique IP address which is used for identification. In this network, computer represents a customer who receives information about the data of pressure and the measurement modules are servers that generate information about the data pressure. In order to connect with the modules computer must have a proper setting of a static IP address.

![Intelligent Pressure Scanner connections](image)

Figure 9. Intelligent Pressure Scanner connections

In order to reduce the length of the hoses and improve dynamic measurement characteristics, model 9016 is designed for installation close to the measuring point. The distance between the object which is used for pressure measurement and electronic pressure scanner can range from a meter to thirty meters. Larger hoses have an impact on dynamic characteristics of transferred measuring air pressure signal.

Electronics are located within a housing which is hermetically sealed against the entry of liquids and dirt. Housing and internal electronics are designed to withstand very high vibrations that are moving in vibrational envelope with peak acceleration of 30 G.

The effect of temperature on the measurement error may be significant if the module is exposed to temperatures outside the range of 0 °C to 60 °C. In this temperature range algorithm acts to correct pressure, and any excess of the work area temperature means uncontrolled increase of errors. [5]
V. DATA ANALYSIS

After setting the correct network properties the Netscanner Unified Startup Software can be started. This program allows system calibration, testing, cleaning and changing the IP address. There is no equipment in the laboratory to calibrate system, only the accuracy can be checked. After checking and obtaining IP address, the program LabVIEW can be started.

Manufacturer designed an application inside LabVIEW that connects to module device and reads the pressure. That application was modified for wind tunnel purpose. There is an interface of the application used for pressure acquisition for Netscanner system. To start the application it is necessary to enter correct IP address.

Air characteristics:
- temperature: \( t = 26,2^\circ C, T = 299,35 \text{ K} \)
- pressure: \( p = 99580 \text{ Pa} \)
- density: \( \rho = 1,1589 \text{ kg/m}^3 \)
- viscosity: \( \mu = 1,8415e - 05 \).

Measuring of surrounding flow speed around airfoil for motor frequency of 35 Hz:
- fluid level difference in U-tube: \( \Delta h = 62 \text{ mm} \)
- pressure difference: \( \Delta p = \rho_{H2O} \cdot g \cdot \Delta h = 1000 \cdot 9,81 \cdot 0,062 = 608,22 \text{ Pa} \)
- airspeed: \( v = \sqrt{2 \cdot \Delta p / \rho} = 32,403 \text{ m/s} \).

Using the sum of all pressure around measuring points, and lift formula we can get the normal component of the lift:
- \( F_N = 71,39 \text{ N} \)

Difference between piezometric harp and scanner is +/-5% because of errors in reading height of harp and inability to accurately measure a harp slope.

The Figures 10. and 11. show a graphs that represents the pressure distribution around airfoil and it is very similar to graph obtained by manual calculating using piezometric harp. Y-axis shows pressure value in PSI and X-axis shows measurement point number. On the right side pressure is shown in decimal number.

VI. CONCLUSION

Use of the system for pressure data acquisition significantly shorten and simplify the process of pressure distribution determination. Measurement results obtained from piezometric harp and those from pressure acquisition module vary in acceptable extent. Intelligent pressure scanner is more accurate device and allows programming in various languages. There is no more need for manual calculations. Application for sensing the pressure created in the LabVIEW program could be upgraded so all pressure around the airfoil could be presented in one coordinate system. It is also possible to make the application to sense all the pressure around airfoil, with given speed and conditions of the atmosphere, to calculate coefficient of pressure, lift and drag for given angle of attack. This system is independent of AT-1 wind tunnel and airfoil within it. In future experiments other airfoils could be used and in different wind tunnels for various testing.

LITERATURE