EXPERIMENTAL MEASUREMENT OF INVERSE FLOW USING FIVE-HOLE PROBE

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Abstract - A new experimental method is proposed to measure the inverse flow using the five-hole probe. Due to limitation of the five-hole probe in measurement of directangle of mean flowfield, the conventional measurement methods are not able to measure the inverse flow. The new proposed experimental method makes able the five-hole probe to measure the inverse flow by installing the probe once windward to the flow and another time by its installing leeward to the main flow. To create an inverse flow, a vertical flat plate is located at center of wind tunnel test section. The experimental tests were carried out in an open-circuit wind tunnel where the free stream velocity is set to a value 24.5 m/s. Moreover, to be sure of right experimental measurement, an incompressible pressure-based CFD code is applied to solve the turbulent flow field around the flat plat and compare the results with those of the experimental measurements.

Keywords - Experimental measurement, Five-hole probe, Inverse flow, Numerical simulation.

I. INTRODUCTION

There are several experimental tools such as Multi-hole probe (MHP), Hot-Wire Anemometry (HWA), Laser-Doppler Velocimetry (LDV) and Particle-Image Velocimetry (PIV), to measure the fluid flowfield.MHP, HWA and LDV are point instruments, whereas PIV can generate information along a plane cutting across the velocity field of consideration.Point instruments require traversing along the domain of interest to map out a velocity field.LDV and PIV require optical access to the point of measurement, which is a limitation to the experimental rig, as well as the range of working media.The hot wire anemometer is the most vulnerable to particulates in the flow and can easily be damaged if not handled properly.Thus, it is not appropriate for industrial applications. However, of all these methods, the MHP is the most robust and reliable tools most appropriate for many industrial applications, that can be operated in opaque fluids that could carry some particulates, and do not need optical access to the point of measurement. But in some cases they may introduce some local or even global interference to the flow [1-3].

MHP is based on the fact that the static pressure varies over a solid surface immersed in the flow, from the maximum value, which is equal to the stagnation pressure to low values the order of the base pressure in the wake of the body. Measuring the pressure at distinct points over the body of a probe can provide all the necessary information on velocity components and in-field pressures. This requires careful calibration. Many different shapes have been employed for the tip of a MHP as for example cones, spherical or cylindrical surfaces or faceted surfaces. These probes must be inserted in the flow at the point where a measurement is required. There are some limitations in flow measurement by the MHP that depend on the dimensions of the tip and the local spatial variations of the flow [4, 5].

The main objective of the present study focuses on validation of proposed experimental method for inverse flow measurement using the five-hole probe.Due to limitation of the five-hole probe in measurement ofdirectangle up to maximum $\pm 50^0$, the conventional measurement methods with installing of the five-hole probe windward to the main fluid stream are not able to measure the inverse flow. The new proposed experimental method makes able the five-hole probe to measure the inverse flow by installing the probe once windward to the flow and another time by its installing leeward to the main flow. This causesthe probe can measure the angles which are in two cones, direct cone and inverse cone (Figure 1).

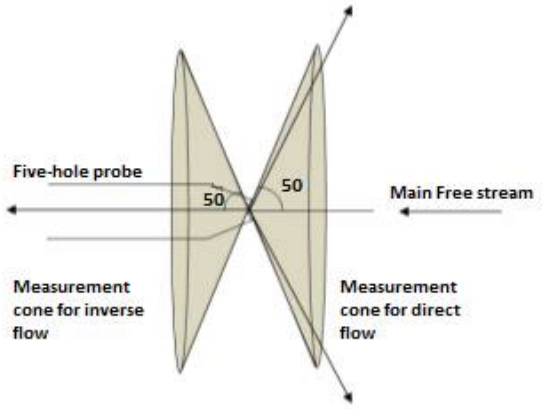


Figure 1.Cone angles measured by the five-hole probe

To create an inverse flow, a vertical flat plate is located at center of wind tunnel test section. The experimental tests were carried out in an open-circuit wind tunnel with a test section of 100×100×180 cm in dimension where free stream velocity can be set to a value 24.5 m/s. Moreover, to be sure of right experimental

measurement, an incompressible pressure-based CFD code is applied to solve the turbulent flow field around the flat plat and compare the results with those of the experimental measurements.

II. EXPERIMENTAL TEST ARRANGEMENT

Experimental Tests were carried out in anopen-circuit wind tunnel laboratory in the Aerospace Engineering Department of Amirkabir University of Technology with a test section of 100×100×180 cm in dimension where free stream velocity can be set to a value 24.5 m/s. To create an inverse flow, a vertical flat plate with 1*0.5 mdimensions is located at center of wind tunnel test section. The plate completely covers half of test section area and makesa suitable inverse flow behind the flat plate. Installation position of the plate in the wind tunnel is shown in figure 2.

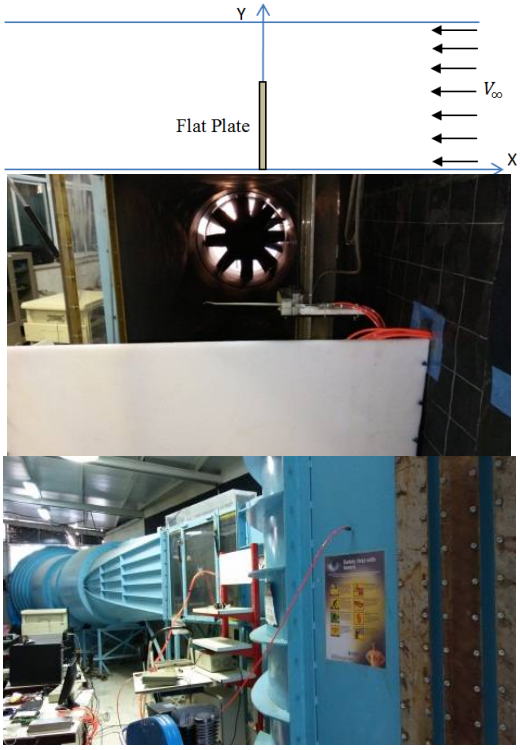


Figure 2. Plate position in the wind tunnel

In order to measure the velocity component and flow angles, a Cobra type five-hole probe is traverse in different points behind the plate. As indicated in figure 3,to measure the inverse flow, once the probe tip is installed forward to main flow and in another test, it is placed backward to the main flow. The five-hole probe moves in different points by installing on a traverse which can move in different sections.In this test, the measurements are performed in two sections behind the plate, X=-20 cm and X=-30 cm, at 24 points (Table 1).



Figure 3: Position of five-hole probe for measurement

X1= -30 cm	Y1 (cm)	Y2 (cm)	Y3 (cm)	Y4 (cm)	Y5 (cm)	Y6 (cm)	Y7 (cm)	Y8 (cm)	Y9 (cm)	Y10 (cm)	Y11 (cm)	Y12 (cm)
	85.5	80.5	75.5	70.5	65.5	60.5	55.5	50.5	45.5	40.5	35.5	30.5
X2= -20 cm	Y13 (cm)	Y14 (cm)	Y15 (cm)	Y16 (cm)	Y17 (cm)	Y18 (cm)	Y19 (cm)	Y20 (cm)	Y21 (cm)	Y22 (cm)	Y23 (cm)	Y24 (cm)
	85.5	80.5	75.5	70.5	65.5	60.5	55.5	50.5	45.5	40.5	35.5	30.5

Table 1: Measurement points behind the vertical flat plate

IV. NUMERICAL SIMULATION

The FLUENT software as an incompressible pressure-based CFD code using finite volume method is applied to solve the turbulent flow field around the flat plat. In present numerical solution, the energy equation is neglected and the continuity and momentum equations are applied [27]. The SST-K-w turbulence models are implemented in this numerical simulation to accurately capture the vortices and swirling of the flow around the geometry. Moreover, an enhanced wall function equation has been selected to improve accuracy of the numerical simulation of the flow behavior near the wall.
Due to simple 2D simulation and no limitation in computational cost, very fine structured grid especially near the plate and wind tunnel walls is used to capture accurate results. 56000 cells are used in the grid and distance of the first grid from the wall is 0.0001 m. The grid and boundary conditions applied in the numerical simulation are shown in figure 4.

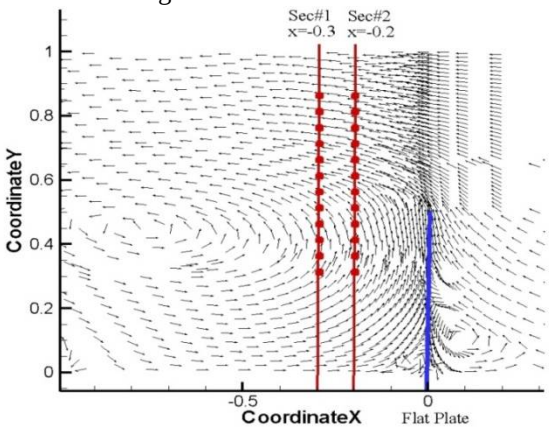
To consider effect of the wind tunnel wall on the results, the no slip boundary condition is applied. Due to the low subsonic velocity in the present experiment, constant velocity magnitude at the inlet boundary and constant static pressure at the outlet surface of the flow field according to the real experimental test are considered. The experimental standard pressure and viscosity are also set in computational fluid dynamics.



Figure 4. Applied mesh and boundary condition for numerical simulation

V. RESULTS

Due to square area section of the wind tunnel and installed conditions of the flat plate, 2D numerical simulation is considered. Inlet velocity of the wind tunnel is 24.5 m/s. Pressure contour and velocity vectors obtained from numerical simulation is shown in figure 5. The large main vortex and inverse flow is obviously indicated behind the vertical flat plate.
Due to limitations of traverse movement, flow measurement by the five-hole probe is performed at several points in two specified sections behind the flat plate, X=-20 cm and X=-30 cm, (Figure 5).where include the inverse flow.The test is performed two times in the specific points in the same conditions: once the probe tip is installed forward to main flow to measure direct flow structure and in another test, it is placed backward to the main flow to measure the reverse flow angles.



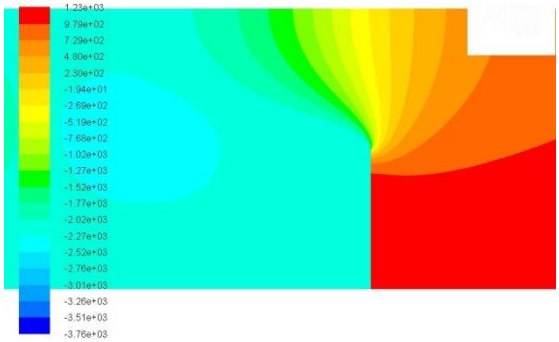
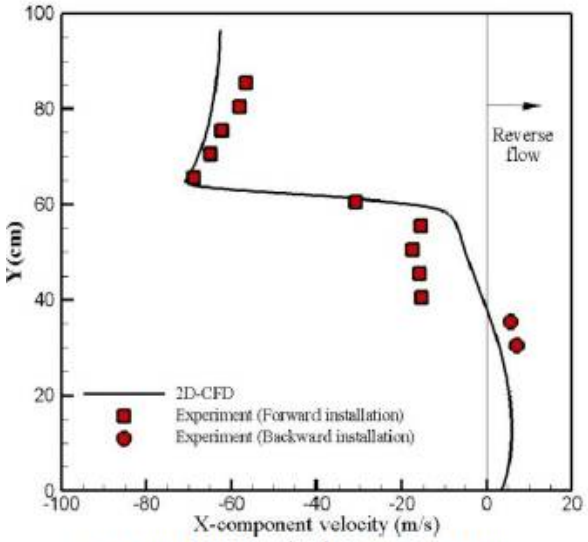


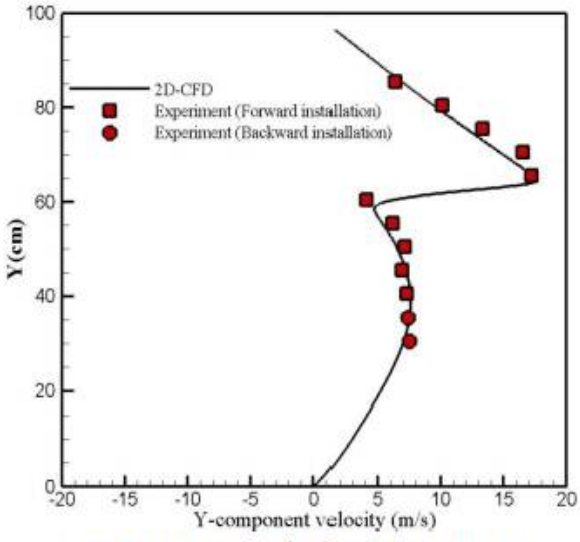
Figure 5.Pressure contour and velocity vectors in flow simulation around the vertical plate

Figure 6 shows comparison of x and y velocity components and pitch angle between captured experimental data and computed numerical results at both sections, X=-20 cm and X=-30 cm. For sure, the test is also carried out at free stream velocity of 26.5 m/s and the same results are captured. Generally, it is founded from numerical and experimental data that the obtained results have desirable trends. As expected, at higher speed which the dynamic pressure has higher value, better agreement between experimental and numerical results is shown. This is due to reducing of pressure sensors accuracy and increasing numerical errors in simulations at lower speeds and pressures. In figure 6, angle and velocity vector of inverse flow are specified by circular symbols and the direct flow by square symbols. Infact, the square symbols are measured by forward installation of five-hole probe and the circular ones

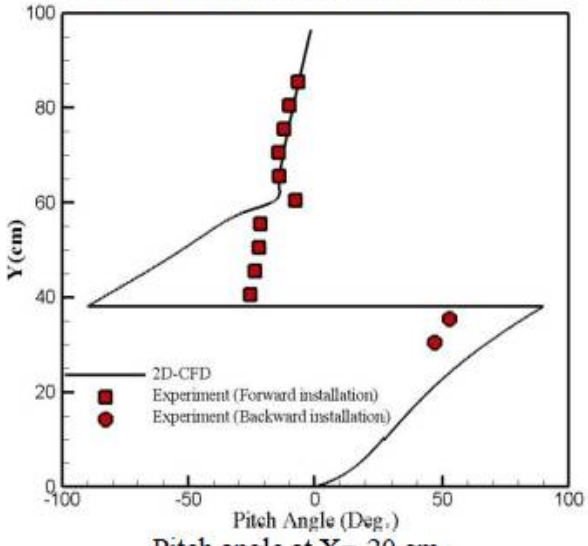
are captured by backward installation. The obtained results show that the proposed method in using five-hole probe can be applicable for measurement of the inverse flow.



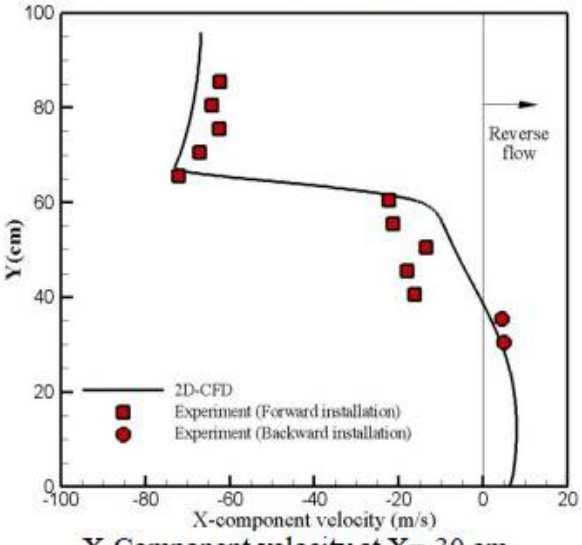
X-Component velocity at X=-20 cm



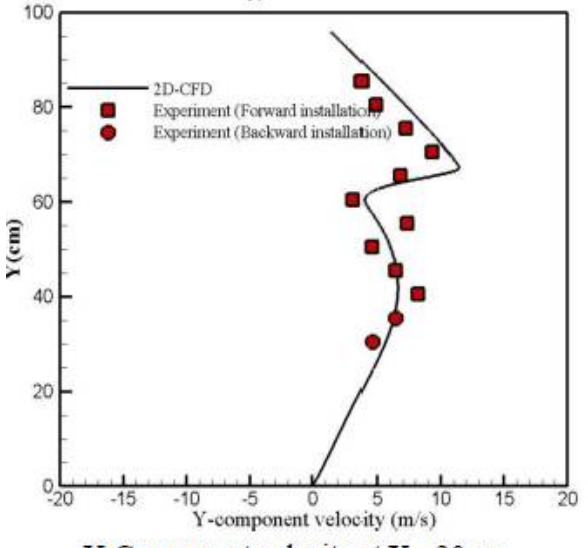
Y-Component velocity at X=-20 cm



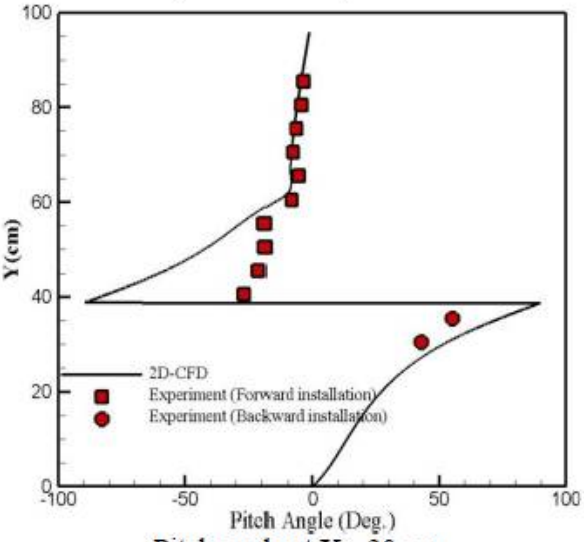
Pitch angle at X=-20 cm



X-Component velocity at X=-30 cm



Y-Component velocity at X=-30 cm



Pitch angle at X=-30 cm

Figure 6. Comparison of measurement velocity components and pitch angle at V=24.5 m/s

CONCLUSION

The main objective of the present study focuses on validation of proposed experimental method for inverse flow measurement using the five-hole probe. The new proposed experimental method makes able the five-hole probe to measure the inverse flow by installing the probe once windward to the flow and another time by its installing leeward to the main flow. To create an inverse flow, a vertical flat plate is located at center of wind tunnel test section. The experimental tests were carried out in an open-circuit wind tunnel where the free stream velocity is set to a value 24.5 m/s. Moreover, to be sure of right experimental measurement, an incompressible pressure-based CFD code is applied to solve the turbulent flow field around the flat plat and compare the results with those of the experimental measurements. Generally, the obtained results show that the proposed method in using five-hole probe can be applicable for measurement of the inverse flow.

REFERENCES

[1] S. Watkins, P. Mousley and G. Vino1, “The Development and Use of Dynamic Pressure ProbesWith Extended Cones of Acceptance (ECA)”, 15thAustralasian Fluid Mechanics Conference, University of Sydney, Australia, December 2004.

[2] D.Telionis and Y. Yang, “Recent Developments in Multi-Hole Probe (MHP) Technology”, 20th International Congress of Mechanical Engineering, Gramado, Brazil November 2009.

[3] I.C. Shepherd, “Mean flow measurement in three dimensions using a four hole pressure probe”, 7th Australasian hydraulics and fluid mechanics conference, Brisbane, August 1980.

[4] S.H. Kim, Y.J. Kang, R.S. Myong, T.H. Cho, Y.M. Park and I.H. Choi, "Calibration of a Five-Hole Multi-Function Probe for Helicopter Air Data Sensors", International Journal of Aeronautical & Space Sciences, Vol. 10, No. 2, November 2009.

[5] J.D. Crawford, "Design and calibration of seven hole probes for flow measurement", PhD thesis in Mechanical and Materials Engineering, Queen’s University, Canada, 2011.

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