Development of Small-Scale Wind Tunnel for Flow Visualization and Thermal-Fluid Experiments

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ABSTRACT: A wind tunnel is commonly used to study flow characteristics through an object, for example, to understand the aerodynamics of airplanes, cars, and trucks. The wind tunnel size varies from small to very large structures depending on the desired applications. The objective of this work is to construct a test rig facility that suits both flow visualization studies with at least 5.0 m/s flow velocity and thermal experiment. Thus, a small wind tunnel was designed with CATIA software, and the flow inside the tunnel was simulated using ANSYS Fluent. The flow condition was also validated using a hot-wire anemometer. The experiment result shows that the constructed wind tunnel induced a similar average with the simulation result. However, it shows an asymmetrical profile because of the surface roughness of the test section.

Keywords: *Wind tunnel; Flow characteristics; Velocity*

1. INTRODUCTION

A wind tunnel is typical used to conduct fluid dynamic experimental studies and this facility can be found in many research centres, educational institutions, and industries. There are different types of the wind tunnel, but a good wind tunnel should be able to measure accurate steady or unsteady data based on physical phenomena of interest [1]. The wind tunnels are classified based on the flow velocity in the test section and the test section size will influence the overall dimension of the wind tunnel, specifically other components such as the diffuser, nozzle and settling chamber [2], [3]. To conduct flow visualization studies using the PIV in the wind tunnel, both open and closed-loop designs can be used. However, the closed-loop wind tunnel requires lesser seeding particles and quickly dispersing particles in the entire tunnel [1]. In this study, a small-scale wind tunnel is constructed by developing a test section that can be also used for heat exchanger experiments. Typical characteristics of heat exchangers can be from 0.5 to 5.0 m/s [4] and this present study aims to achieve at least 5.0 m/s in the test section. Suitable material for the test section is proposed to match the objective of this wind tunnel design.

2. METHODOLOGY

The main components of the in-house fabricated wind tunnel can be designed based on some calculations as suggested in the past literature [2]. Figure 1 shows an assembly drawing of the wind tunnel designed by using CATIA V5R21 software.

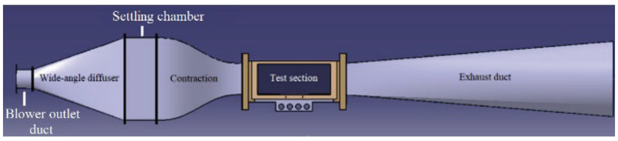

Figure 1 An assembly drawing of the wind tunnel

The test section in Figure 2 was specially designed so that it can be used for different experiments, e.g., flow dynamics experiment using a hot-wire anemometer and PIV, and providing a heat source when necessary. It was made using different materials: aluminium and Bakelite. This study had considered aluminium with four-manifolds as a part of the test section floor. This part can easily heat any conductive specimen on the top once hot liquid is streaming through the manifolds.

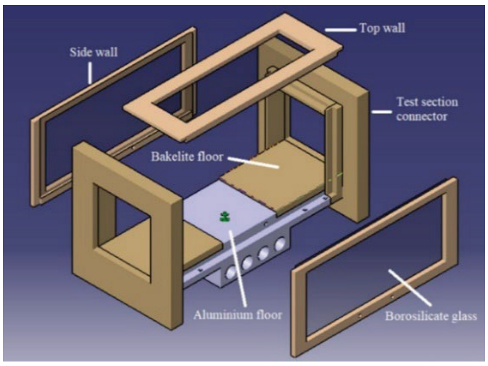

Figure 2 Test section (Exploded view)

Bakelite was chosen due to its high heat resistance (120°C of continuous heating), stiff and strong to be used as the test section wall. However, to allow optical access inside the test section for the use of thermal camera or laser diagnostic equipment, the top and side walls of the test section were installed with borosilicate glass (3 mm thickness). Also, to achieve at least 5.0 m/s in the test section of 100 mm (height) x 100 mm (width), a suitable blower must be selected. This study proposed a high-pressure blower (AIRSPEC, ARC 629, Power = 3.0 kW). The blower can discharge the airflow up to 376 m^3/h, thus a calculation based on its outlet duct diameter of 0.06 m shows that the inlet air velocity right before the diffuser would be 40 m/s. This value was used as the input velocity in our CFD simulation (ANSYS Fluent v15.2) for a 2D domain with the same structure as shown in Figure 1. To capture the characteristics of the flow, the k- ε model was considered and the outlet was defined with zero pressure. A porous zone was also considered to represent a honeycomb in the settling chamber. The result shows an average of 5.0±1.0 m/s air velocity inside the test section from Figure 3. In the experiment, the air velocity from the blower can be adjusted by using an inverter (TECO Inverter F510).

Figure 3 Velocity contours in the test section

3. RESULTS AND DISCUSSION

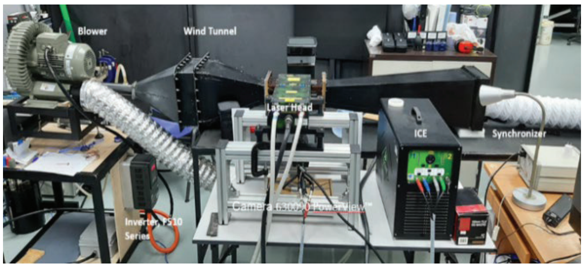

Figure 4 Complete wind tunnel construction

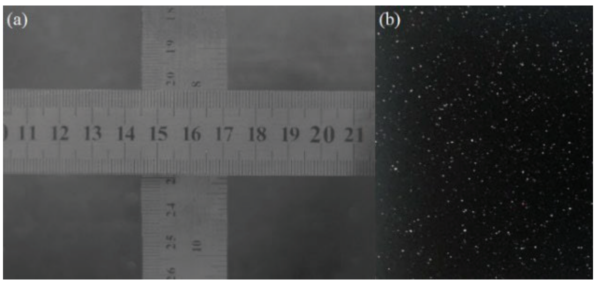

Figure 5 (a) Standard image and (b) Raw PIV image

Figure 4 shows the in-house fabricated wind tunnel with the PIV system where the outlet of the wind tunnel is connected to a flexible duct and returns to the blower, making it a closed-loop wind tunnel. This construction may avoid the dissipation of the seeding particle from the PIV experiment to the laboratory environment. For the experiments with temperature, the four-manifolds can be connected to a hot fluid supply, providing heat from underneath of the test section. Figure 5 shows the images seen through the wall of test section, which were captured using a charged-couple device (CCD) camera under different room brightness. Figure 5 (a) shows a calibration of the camera's field of view with the size of test section in a bright room. Meanwhile, Figure 5 (b) shows the image of illuminated seeding particles by the laser without any reflection. This proved the suitability of this test rig with the PIV system. The flow characterization was conducted by investigating the velocity profile inside the test section using a hot-wire anemometer (HT-9830; Accuracy: ±3%+0.2 m/s). Figure 6 shows the velocity profile (a ratio of local velocity over the inlet velocity from the test section entrance) in the test section is asymmetric, unlike the ideal turbulent velocity profile in a common wind tunnel. At the middle of the velocity profile, the value is 5.0 m/s, following our CFD estimation. However, the asymmetrical profile occurs as expected due to the surface roughness of the bottom wall (h_o/h_{inlet} = 0) made bakelite as compared to the borosilicate glass at the top wall (h_o/h_{inlet} = 1.0). This velocity profile should be used as a reference case when using this wind tunnel for future experiments.

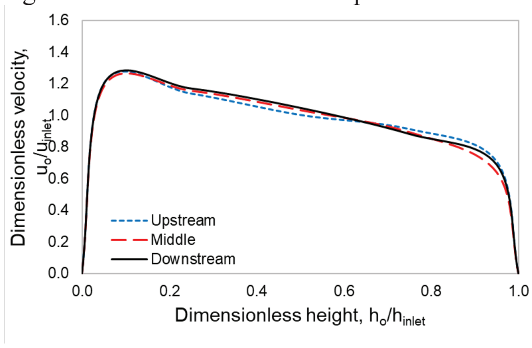

Figure 6 Velocity profile in the test section

4. CONCLUSION

A wind tunnel has been successfully designed to be used with laser diagnostic equipment. Its small size with a closed loop design would make the PIV experiments more feasible. The entire test section can be captured at once, reducing the time needed for experiments and analysis. A heat source can be also added for other series of experiments.

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