Design Optimization and Experiment Verification of Air Sensor's Calibration Tool

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***Abstract*—This research has developed a high sensitivity of the airflow sensor in detecting the changes in the environment where the custom calibration tool is required to proceed on the testing stage. This paper investigates the correlation of airflow velocity (v) and the angle of the flap sensor (º) created by the airflow sensor. In order to verify the correlation, a tool (jig) to hold the air sensor in the wind tunnel was developed to validate the result. The findings show that the re-design process has been done to the jig to sustain the air sensor position for the high speed region. A few parameters have been prioritized to eliminate the possibility of producing a less accurate result.**

***Index Terms*—air sensor, jig, calibration, flap sensor**

I. Introduction

Nowadays, our life is much simplified with technology development and innovation. Among the most developed technologies are sensors that operate under certain condition. Different types of applications require different types of sensors to collect data. The sensor is a sophisticated device that is frequently used to detect and respond to electrical or optical signals [1]. A sensor converts physical parameters into a signal which can be measured electrically.

However, the problem is the accuracy of the airflow sensor for engineer and researcher. There are a few major factors that need to be considered in order to design and develop a sensor with higher sensitivity such as temperature, wind speed, the direction of the wind, quantity of force and the movement. Thus, this project is intended to design and fabricate a jig that can stand in high-speed airflow movement of the wind tunnel. The wind speed is between 0 to 110km/h as the Malaysia speed limit [2].

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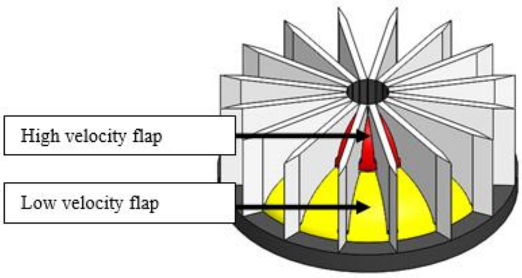

Figure 1. Design casing of airflow sensor

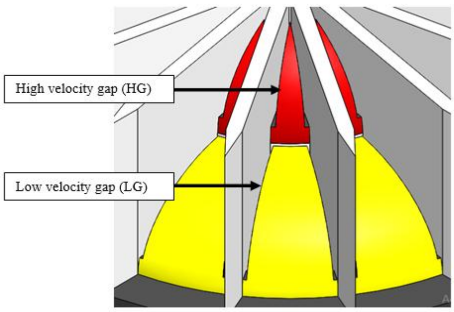

Figure 2. Close up design of high velocity gap and low velocity gap

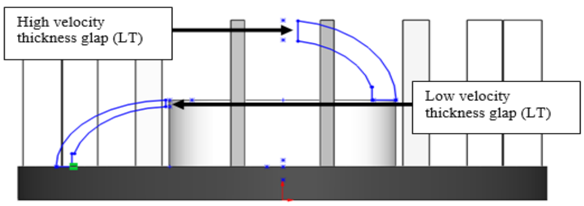

Figure 3. Sketch of high and low velocity thickness flap

Fig. 1 to 3 shows the developed high sensitive airflow sensor consists of two regions which are high and low velocity [3]. The region is covered with two types of flap structure to detect the airflow changes from the deflection [1]. The airflow model also can cover 360 degrees of incoming air in order to achieve better coverage of airflow changes [4].

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As to design and fabricate the prototype, the verification process only focuses on material and direction of wind speed which is become the main factor because it may affect the performance of the structure. So, the testing and simulation are important to find out the material can withstand the airflow movement in wind tunnel. The wind speed is set 0 to 110km/h, the main point is to focus on the effect of laminar flow on the structure surface. Any changes and effect on the structure should be recorded to minimize the error.

The specific tool was designed to accommodate the necessity of the placement for the airflow sensor in an accurate position inside the wind tunnel. The jig also needs to withstand the speed of 110km/h without any obstruction in rotation movement or major vibration that may occur during the testing.

II. Methodology

A. Design Prototype Model

A jig's primary purpose is to provide repeatability, accuracy, and interchangeability in the manufacturing of products. Generally, Fixtures are used to securely locate (position in a specific location or orientation) and support the work, ensuring that all parts produced using the fixture will maintain conformity. In experimental fluid mechanics, a jig is used to hold the testing model in the wind tunnel. The jig is designed to support the model weight and the aerodynamic loads generated by models with the least possible flow interference. The system is provided as a unit, allowing easy removal to accommodate other support systems in the test section or for maintenance.

In this project, the jig is used to hold the structure of the air sensor. The design is using CATIA software and must be able to withstand the wind speed in the wind tunnel during the process. The jig has 2 main components which are a slot to grip the air sensor during the process in the wind tunnel. The dimension is 5mm × 5mm to ensure the base of the air sensor can locate in the slot. The second component is the hole with thread to mount the jig and the rod of a wind tunnel. The diameter is 4mm with depth 10mm and it is firmly attached to the rod to prevent any movement on the jig during the experiment as shown in Fig. 4.

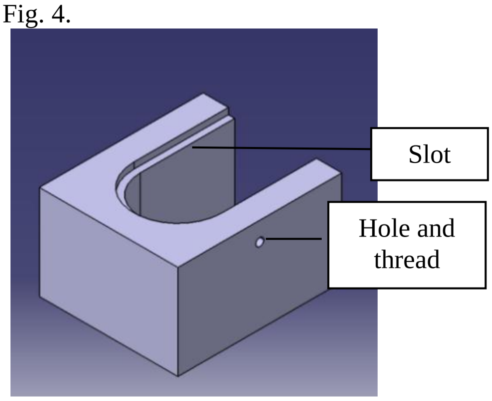

Figure 4. Design of the jig

B. Fabrication

In order for the fabricate, one of the causes manufactures that could happen is due to the material of the jig holder itself. The Acrylonitrile Butadiene Styrene was used due to the ability to sustain the load, the low in cost and aesthetic value factor. ABS (Acrylonitrile Butadiene Styrene) is another commonly used 3D printer material. Best used for making durable parts that need to withstand higher temperatures. In comparison to PLA filament, ABS plastic is less brittle and more ductile. It can also be post-processed with acetone to provide a glossy finish. When 3D printing with ABS filament, a heated printing surface is recommended, as ABS plastic will contract when cooled leading to warped parts.

Acrylonitrile Butadiene Styrene is great in absorbing shock [5]. It can reduce vibration for the jig during testing in the wind tunnel. The airflow created by the fans that are entering the tunnel is itself highly turbulent due to the fan blade motion. In general terms, in turbulent flow, unsteady vortices appear of many sizes which interact with each other, consequently drag due to friction effects increases [6]. Thus, the motion between the airflow movement and the jig will create the vibration which affects the data.

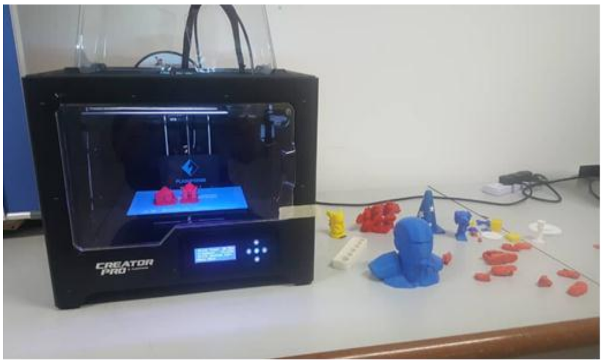

Figure 5. 3D printer flashforge

In the fabrication process, the jig holder is done using primarily 3D printers. The Flashforge Creator 3D Printer was used to create a prototype. This 3D printer offers excellent quality when it comes to printing 3D objects. The print results are so accurate. It would produce a fine surface for holder jig. Besides, it also includes a touchscreen panel that is very easy to see and to work with. The digital interface includes large virtual buttons that are easy for a finger to touch. This 3D printer offers convenient and cost-effective filament management. FlashForge Finder filament spool chamber is removable, making spool installation a breeze as shown in Fig. 5.

The bolt and nut are used to make sure the clamp is tight and can hold the structure from wind resistant in the wind tunnel. It is stainless steel fasteners and most importantly, corrosion resistant. The specification of the bolt and nut comes with a nominal size of TM2 and thread pitch of 0.4 mm.

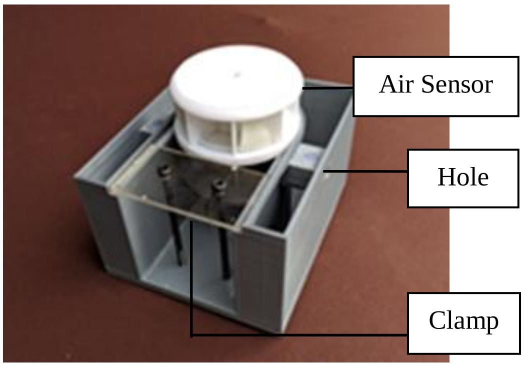

Figure 6. The first prototype of jig

Furthermore, another component is the clamp which is used to hold and fixed the air sensor from any movement. The clamp was fabricated by using polymers of methyl methacrylate (PMMA) as well as by trade names Perspex among several others, is a transparent thermoplastic often used in sheet form as a lightweight or shatter-resistant alternative to glass. It has a density of 1.17–1.20 g/cm3, which is less than half that of glass [7]. It also has good impact strength, higher than both glass and polystyrene as shown in Fig. 6.

For further improvement of the jig, rubber sheet can be used at the connection joint to reduce the vibration that comes from the high-speed airflow movement. This step may increase the data accuracy of airflow changes detection.

C. Sensor Test

Sensor test function to verify the sensitivity of the new flex sensor before the experiment. The flex sensor is a sensor that can measure the amount of deflection. In this case, the flex sensor is used to determine the value of voltage against the angle of deflection. Four sensors need to test the sensitivity and compare the result.

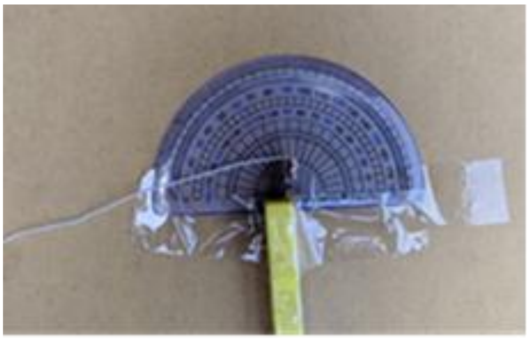

Figure 7. Setup for Sensor test

The thread will apply by force to ensure the flex sensor can bend as shown in Fig. 7. The flex sensor was connected to Arduino to get the voltage value for each angle of deflection. The data angle of deflection and voltage output must be recorded and compare with other sensors to ensure it can function during experiment testing.

D. Experimental Setup

A prototype air sensor is testing in the low-speed tunnel, AF100 Subsonic Wind Tunnel. This model offers a range of additional models and instrumentation to extend the experiments, including a data acquisition system [8]. The working section of the tunnel is a square section with a clear roof, sides and floor. The sides are removable. The floor and each side panel have a special position to support the optional wind tunnel models. Supplied with the wind tunnel are a protractor and a model holder to support and accurately adjust the angle of any models fitted.

For the wind speed, AF100 Subsonic can reach 129 km/h for the maximum speed. However, for this experiment, the wind speed is set between 0 to 40m/s (0 to 110km/h) based on the Malaysia speed limit.

The jig and sensor are located in the wind tunnel which has dimension $305 \times 305 \times 600$ inches as shown in Fig. 8. Air enters the tunnel through an aerodynamically designed effuse (cone) that accelerates the air linearly [9]. A separate control and instrumentation unit controls the speed of the axial fan (and the air velocity in the working section).

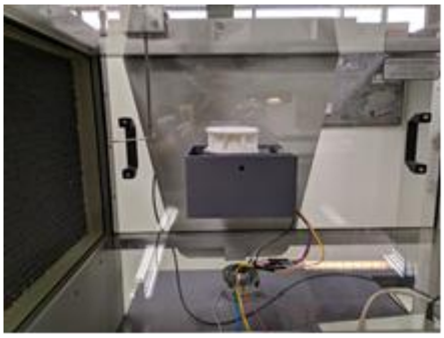

Figure 8. Position of jig in the wind tunnel

E. Improvement and Optimization

In this stage, after the original design has been confirmed not meeting the criteria of the high sensitivity of sensor, improvement and optimization was done to enhance the performance of the jig. The high resultant air from the wind tunnel give more vibration and cause a movement on the jig. In order to achieve the objective, the aerodynamic design is a solution to minimize the vibration on the jig. Another improvement is to redesign the clamp which is located on the slot of the jig. The clamp used to maintain the position of air sensor on the slot surface. The structure of the air sensor must be stable and avoid any interference as it will affect the sensitivity of the flex sensor. Moreover, the cylinder function to protect the cable from exposure to the wind in the tunnel as shown in Fig. 9. This cable is connected with the Arduino system that functions to read data input from an angle of deflection on a flex sensor. For the material same as before jig which is used Acrylonitrile Butadiene Styrene to maintain the mass and strength of the jig.

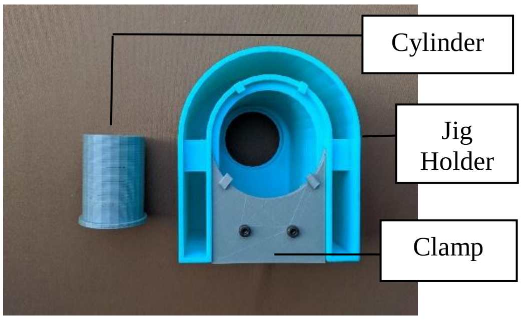

Figure 9. Optimization of the jig components

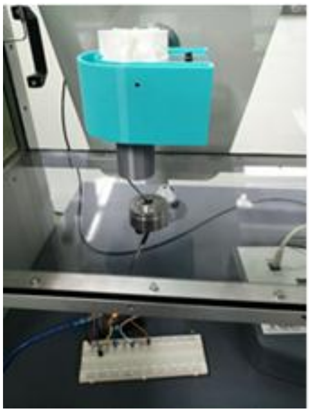

Figure 10. Experimental testing

III. Result and Discussion

A. Result for Sensor Test

Table I presents the results obtained from the preliminary analysis of the flex sensor. The data show a positive correlation between an angle of deflection of flex sensor and output voltage. This finding supports previous research into this brain area which the higher the speed of wind or air velocity will increase the value of pressure and the total deformation [1]. The result shows that the developed jig is suitable to collect the data accurately without producing major vibration to the sensory structure that may affect the integrity of the data obtained.

TABLE I. Sensor 1 Voltage Reading Respective to Angle Deflection

Angle, º	Voltage,V
0	-13
10	10
20	26
30	44
40	67
50	100
60	104

B. Experimental Result

Based on the experiment, the jig can withstand at wind speed 110km/h and the clamp can grip an air sensor [10]. Besides, the voltage value also consistent because there is no interruption from the wind. The cylinder covers up all the wire from exposure to the wind during experiment occur as shown in Fig. 10. The design of the jig also gives an impact to reduce the effect of vibration from air resistance.

Aerodynamics design is the science of the way air moves, and also simply the way an object's shape affects how it moves through the air [11]. The curved profile of the jig deflects airflow, forcing some air to separate and reducing drag force.

Table II shows the results of the low flap sensors that have been tested in the wind tunnel. The wind speed in the wind tunnel was set between 0 to 110 km/h to observe the sensitivity of the sensor for each iteration. Sensor 1 to 4 data was recorded to check to consistency and trend of the data throughout the interval of the speed change. However, Sensor 1 shows the inconsistency of the data which doesn't reflect the voltage changes. In the other hand, Sensor 2, 3 and 4 show the increasing trend between 0 to 60 km/h. The data can be mapped to the characterization of the voltage changes in different speed for the low-speed region [12].

TABLE II. Experiment of the Air Sensor in the Wind Tunnel

Wind speed, (Km/h)	Voltage, V			
	Sensor 1	Sensor 2	Sensor 3	Sensor 4
0	1	11	13	17
10	0	12	13	17
20	1	12	13	17
30	1	13	13	20
40	2	13	13	22
50	-6	14	13	29
60	-4	14	22	32
70	-5	14	17	29
80	-4	14	17	36
90	-1	14	14	31
100	0	15	17	32
110	3	15	17	37

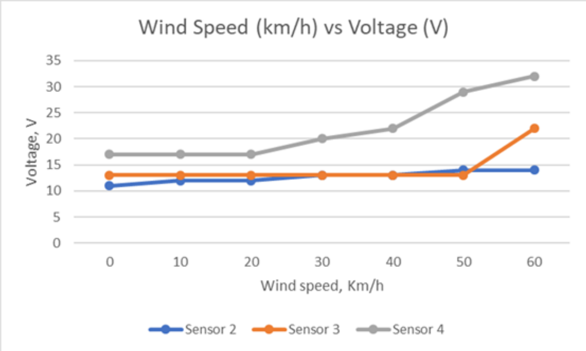

Figure 11. Relationship between wind speed (km/h) vs voltage (V)

Fig. 11 shows the trend of the voltage changes between 0 to 60 km/h. The testing is done at the low-velocity speed region to capture the voltage changes. This also verifies that the data is inconsistent for speed above 70 km/h since the structure was created to fulfill the criteria of the low-speed region only.

IV. Conclusion

The present project has developed the jig to test the air sensor in the wind tunnel. In this project, the verification is shown in Table I and II during the experimental testing of the jig and able to characterize the small change of air flow that acting on the model structure. Moreover, the results of this investigation show that the structure model can withstand a high wind speed in the wind tunnel. This can be proved that the jig was able to reduce a vibration effect on the structure of the air sensor from air resistance at high-speed velocity. The improvement of the jig also prevents the structure from throwing. The main cause is the turbulence flow in the wind tunnel which is in high velocity give an impact to the jig. In turbulent flow, the fluid layers do not move in a straight line. The fluid moves randomly in a zigzag manner. In the high velocity, this flow produces vibration to the jig surface because of the adjacent layers of the fluid cross each other and do not move parallel. Thus, the material and design were important to overcome this problem.

Conflict of Interest

The authors declare no conflict of interest for the research that have been done towards submission of this paper.

Author Contributions

Authors M. D. Amari, S. C. Abdullah and M. Azziem have lead the work for the research and technical paper. Authors. F. A. Aziz have run the testing and collected the data from the experiment. In overall, all authors had approved the final version for the technical paper.

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