Analysis of subsonic wind tunnel with variation shape rectangular and octagonal on test section

by Ismail Ismail

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Abstract. The need for good design in the aerodynamics field required a wind tunnel design. The wind tunnel design required in this case is capable of generating laminar flow. In this research searched for wind tunnel models with rectangular and octagonal variations with objectives to generate laminar flow in the test section. The research method used numerical approach of CFD (Computational Fluid Dynamics) and manual analysis to analyze internal flow in test section. By CFD simulation results and manual analysis to generate laminar flow in the test section is a design that has an octagonal shape without filled for optimal design.

1. Introduction

The need for wind tunnels to solve complex aerodynamics problems is still needed today. The increasing need for fuel in vehicles requires an improvement in vehicle aerodynamics with the aim of more effectively and efficiently to save energy [1]. Upgrade force down on aerodynamics has grown rapidly especially on F1 racing cars. Aerodynamic forces are able to push the tire force against the road and as a result will increase the speed of the vehicle. To increase the downward force can be installing a spoiler. F1 car designers create their own wind tunnel to be able to conduct intensive research in improving vehicle aerodynamics [2]. Low open type wind tunnel is one easy way to solve aerodynamic problems. A CFD approach is also necessary to study the characteristics of aerodynamics in vehicles and wind turbines useful for power generation [3]. The correlation of clogging factors in wind tunnel experiments with Savonius wind turbine media in this study provides evidence of increased blockage correction in the range of 1-10% with an increase in the ratio of speed and the ratio of blockages, results show that for a deviation ratio approaching 10 and a speed ratio below 0.5 in the open-type test section [4]. CFD is a science that studies how to predict fluid flow, heat transfer, chemical reaction and other phenomena with solving mathematical equations. The fluid equation is built and analyzed with partial differential equation which explains the laws of mass conservation, momentum and energy [5].

Construction and testing of subsonic model wind tunnels with dimensions of 0.9 m x 0.9 m and having a test length section of 1.35 m obtained a maximum speed of 28 m/s [6]. The stable flow quality of a modified transonic wind tunnel for NACA 0012 produces the same surface pressure distribution and moment force when compared to other wind tunnel data [7].The effect of the strut shape on the diamond with the cylindrical cross section in subsonic wind tunnel result in a diamond shaped strut turns out to have a smaller lift force [8]. Experiments on turbulence intensity reduction in subsonic wind tunnels used a working air fluid, frequency and statistical analyzes were performed to obtain results in

accordance with experimental findings [9]. The CFD simulation uses a combination of honeycomb for the management of turbulence intensity in subsonic wind tunnel using different length of honey comb, cell shape and screen with different open area ratio, obtained in accordance with the experimental and theoretical results [10]. Methods to improve the distortion of offshore wind flow using CFD simulations and wind tunnel tests concluded that the horizontal wind speed generated at an altitude of 80 m above sea level was 16% lower than the wind speed at 80 m above the island [11]. Studies on the performance of vertical axis wind turbines tested on a wind tunnel obtained similar results when installed on an electrical installation [12]. Mach number on wind tunnel tested which is affective by noise obtained at DNS (direct numerical simulation) that phase speed decreases at low frequency [13]. Modifications open circuit wind tunnels is conducted by varying some design contraction sections, test sections and diffuser section by using the simulation CFD [14]. CFD with rectangular model showed able to replicate wind tunnel measurements for velocity, turbulence intensity and pressure coefficient which have errors below 10% [15].

    In this paper, tells what dimensions are most optimal for the design of rectangular or octagonal wind tunnel models to produce laminar flow and tells the maximum length of an optimal wind tunnel. The objectives of this study is to obtain a low and distributed turbulence current as well as produce winds that correspond to the design on the test section so that it can be used to analyze the specimens aerodynamically.

2. Methods
Methods the present computational and manual analysis is to validate result computation. The detail of each works is explained in detail as follows.

2.1. Computational work
The equation used in CFD is continuity [16].

$$\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z};\tag{1}$$

x-momentum.

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=\rho g_x-\frac{\partial P}{\partial x}+\frac{\partial}{\partial x}\left(2\mu\frac{\partial u}{\partial x}+\lambda\vec{V}.\vec{V}\right)+\frac{\partial}{\partial y}\left[\mu\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)\right]+\frac{\partial}{\partial z}\left[\mu\left(\frac{\partial w}{\partial x}+\frac{\partial u}{\partial z}\right)\right];\tag{2}$$

y-momentum.

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=\rho g_y-\frac{\partial P}{\partial y}+\frac{\partial}{\partial x}\left[\mu\left(\frac{\partial v}{\partial x}+\frac{\partial u}{\partial y}\right)\right]+\frac{\partial}{\partial y}\left[2\mu\frac{\partial v}{\partial y}+\lambda\vec{V}.\vec{V}\right]+\frac{\partial}{\partial z}\left[\mu\left(\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y}\right)\right];\tag{3}$$

z-momentum.

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=\rho g_z-\frac{\partial p}{\partial z}+\frac{\partial}{\partial x}\left[\mu\left(\frac{\partial w}{\partial x}+\frac{\partial u}{\partial z}\right)\right]+\frac{\partial}{\partial y}\left[\mu\left(\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y}\right)\right]+\frac{\partial}{\partial z}\left(2\mu\frac{\partial w}{\partial z}+\lambda\vec{V}.\vec{V}\right);\tag{4}$$

Equations 1 to 4 are used to calculate the fluid momentum value in the wind tunnel on the x axis, y-axis and then z-axis.

The condition of the air fluid properties used in the simulation is shown in table 1. Boundary conditions for wind tunnel air speed 5.8 m/s and then assume pressure on the outside of the wind tunnel 0 Pascal :

Table 1. Computation Condition

Computation Condition		
Model settings		3D, Steady
Fluid		Air
Fluid Properties	Density	1.225 kgm^{-3}
	Viscosity	1.7894 e-05 kgm^{-1}s^{-1}
	Cp	1006.43 Jkg^{-1}K^{-1}
	Thermal Conductivity	0.0242 Wm^{-1}K^{-1}
Boundary Condition	Velocity Inlet	5.8 ms^{-1}
	Pressure Outlet	0 Pascal

2.2. Manual Analysis

Table 2 describes the variation of wind tunnel design of rectangular and octagonal models. In these study variations in the test section with rectangular and octagonal forms to obtain a flow that produces a low turbulence value in the test section.

Table 2. Variations test section wind tunnel

Section	All dimension are in (m)			Information
	Length	Height	Width	
VARIATIONS 1	Rectangular shaped test section and fillets throughout the wind tunnel			
settling chamber	0.613	1.226	1.226	+ fillet 0.2
Honeycomb	DH = 0.05	L = 0.3	Thk = 0.003	
Contraction (type 1)	0.9	1.226	1.226	+ fillet 0.2 ; AR = 6.073
Test section	1.0	0.5	0.5	+ fillet 0.2
Diffuser	4.143	1.226	1.226	+ fillet 0.2 ; AR = 6.073
VARIATIONS 2	Rectangular shaped test section and fillets throughout the wind tunnel			
settling chamber	0.613	1.226	1.226	+ fillet 0.25
Honeycomb	DH = 0.05	L = 0.3	Thk = 0.003	
Contraction (type 1)	0.9	1.226	1.226	+ fillet 0.25 ; AR = 4.174
Test section	1.2	0.6	0.6	+ fillet 0.25
Diffuser	3.572	1.226	1.226	+ fillet 0.25 ; AR = 4.174
VARIATIONS 3	Rectangular shaped test section and fillets throughout the wind tunnel			
settling chamber	0.613	1.226	1.226	+ fillet 0.25
Honeycomb	DH = 0.05	L = 0.3	Thk = 0.003	
Contraction (type 1)	0.9	1.226	1.226	+ fillet 0.25 ; AR = 3.036
Test section	1.4	0.7	0.7	+ fillet 0.25
Diffuser	3.0	1.226	1.226	+ fillet 0.25 ; AR = 3.036
VARIATIONS 4	Octagonal shaped test section throughout the wind tunnel			
settling chamber	0.613	1.225	1.225	
Honeycomb	DH = 0.05	L = 0.3	Thk = 0.003	
Contraction (type 2)	0.9	1.225	1.225	AR = 2.344
Test section	1.4	0.8	0.8	
Diffuser	2.43	1.225	1.225	AR = 2.344
VARIATIONS 5	(Cross section SC, Ct, TS = octagonal; DF = circle)			
settling chamber	0.543	1.086	1.086	
Honeycomb	DH = 0.05	L = 0.3	Thk = 0.003	
Contraction (type 2)	0.9	1.086	1.086	AR = 2.406
Test section	1.4	0.7	0.7	
Diffuser	3.0	Ø = 1.225		AR = 2.901

The continuity equation is a simple mathematical statement of the principle of mass conservation law [15]. In the continuity equation explains that the fluid flow velocity is

inversely proportional to sectional area. In a pipe have a small sectional area then a high fluid flow rate.

$$A_1 V_1 = A_2 V_2 \qquad (5)$$

3. Results and discussion
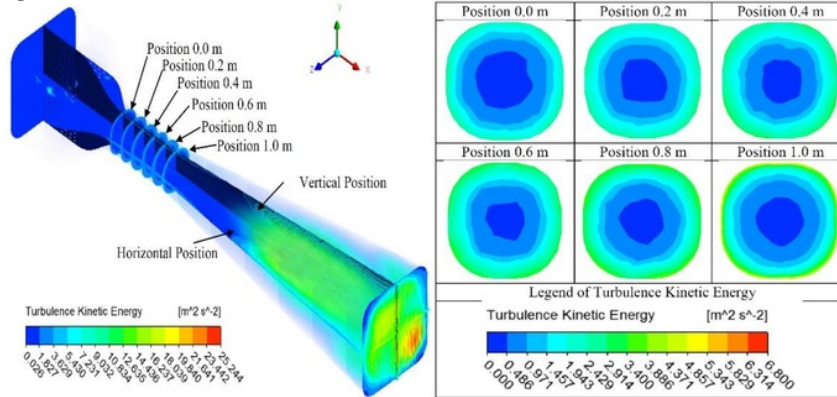
3.1. Computational work

Figure 1. Turbulence kinetic energy for variation shape 1

Figure 1 shows profile turbulence kinetic energy variation 1 test section in rectangular shape of fillet at corner, the result of CFD simulation shows that the value of turbulence kinetic energy 0.486 m^{2}s^{-2} decreased at position 0.6 meter then maximum value at position 1 meter.
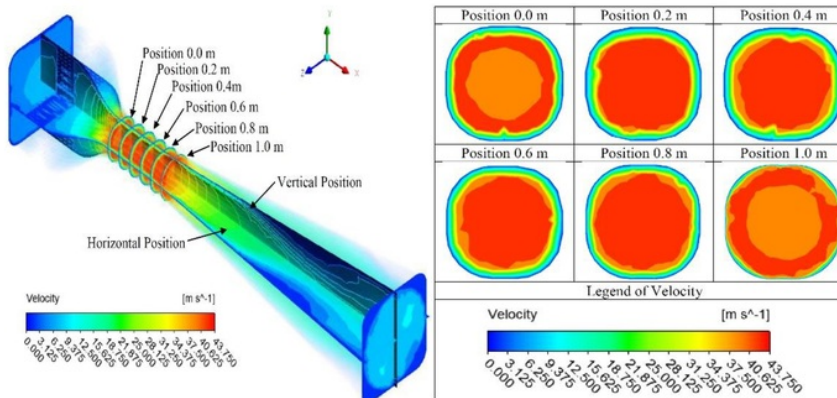
Figure 2. Velocity for variation shape 1

The velocity of the air fluid in the rectangular test section is shown in figure 2 the air velocity distribution is uniform at 0.2 m, 0.4 m, 0.6 m and 0.8 m positions in the inlet 0 m and the outlet 1 m occurs the not uniform of the fluid velocity.
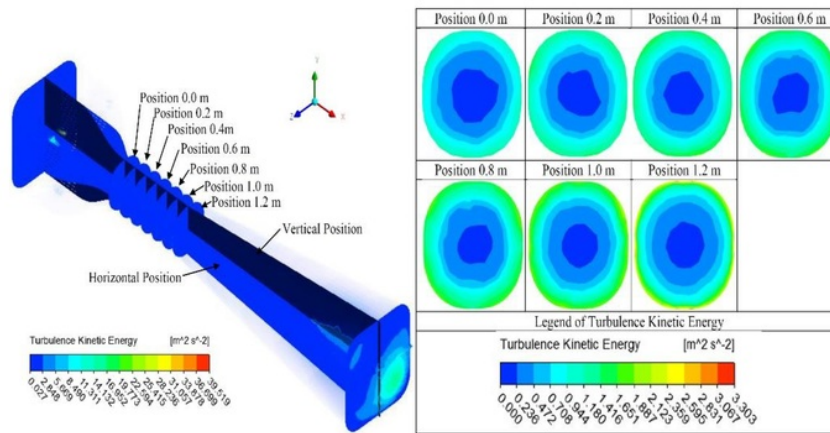
Figure 3. Turbulence kinetic energy for variation shape 2

Figure 3 shows a turbulent kinetic energy simulation that has a 0.25 meter fillet at the rectangular corner. The value of turbulent kinetic energy has increased in the position of 0.6 meters to 1.2 meters on the side near the wind tunnel wall.
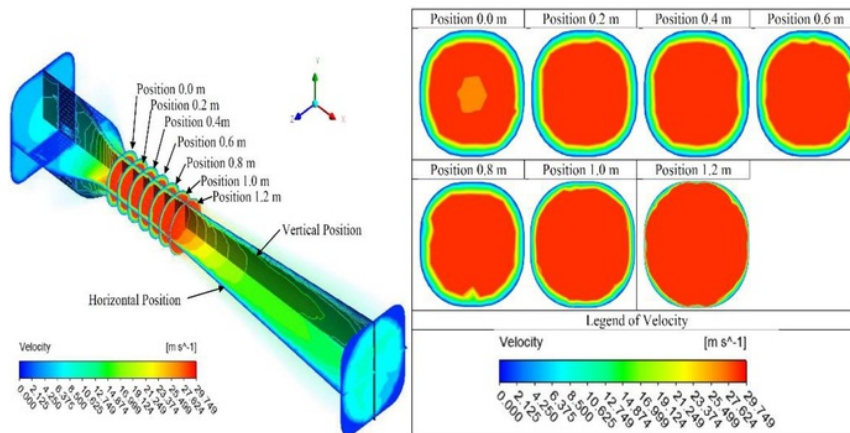

Figure 4. Velocity for variation shape 2

The fluid flow velocity that blows on the wind tunnel is shown in figure 4, for the position of 0 meter visible unstable speed then at the next position the fluid velocity uniformity.
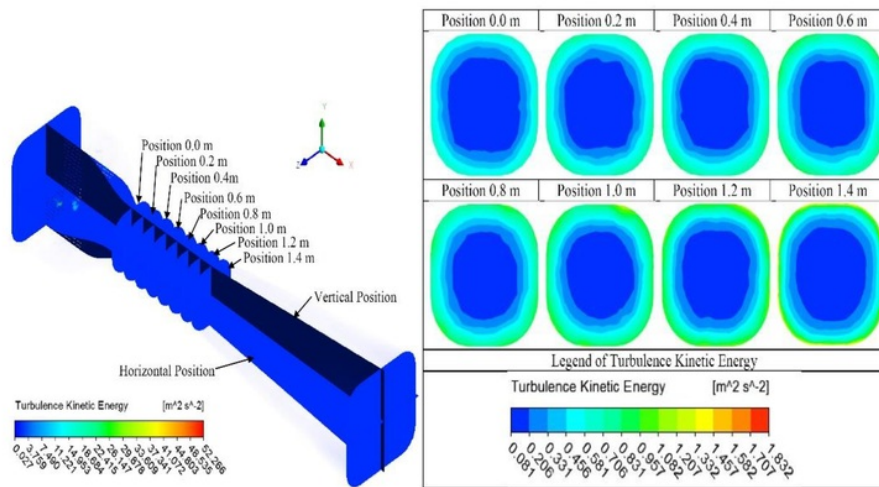
Figure 5. Turbulence Kinetic Energy for Variation Shape 3

At the 3 variations shown in figure 5 tells the turbulent value of kinetic energy has increased in the wall of the wind tunnel at the position of 1 m to 1.4 m.
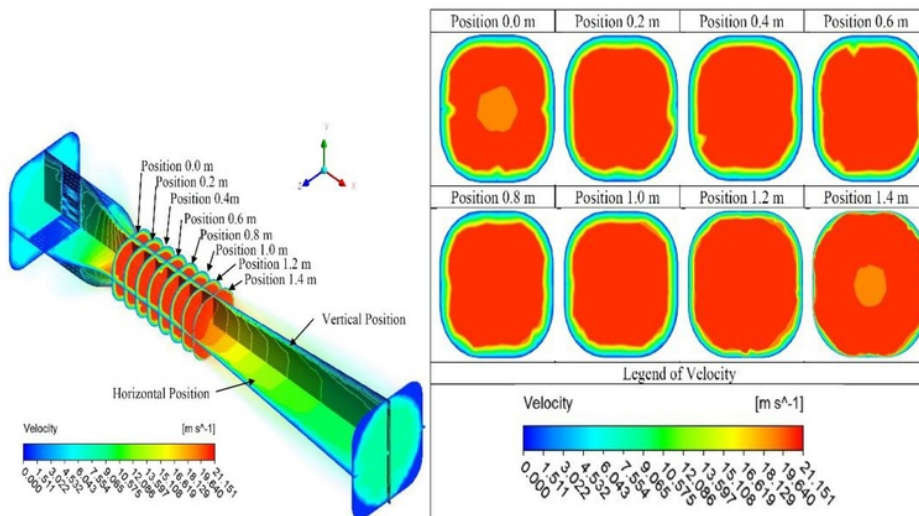

Figure 6. Velocity for variation shape 3

Figure 6 describes the results of the air fluid velocity contour flowing in the test section at positions 0 meters and 1.4 m does not provide uniform flow.
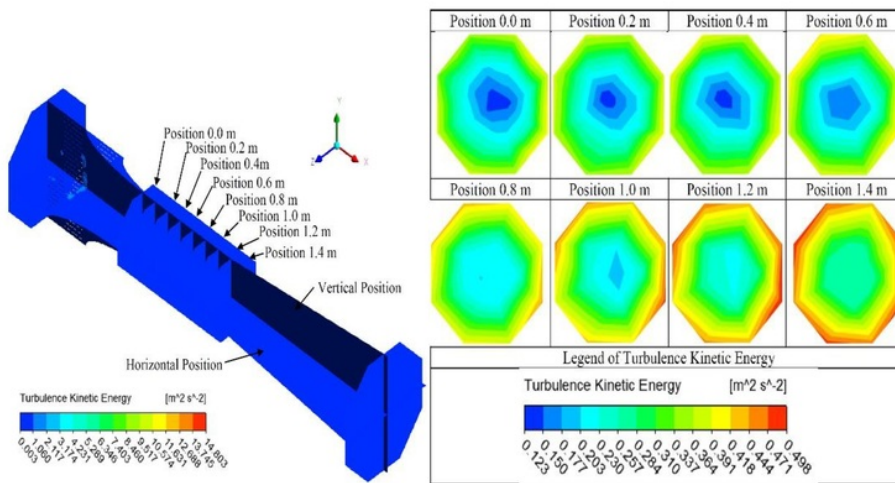
Figure 7. Turbulence kinetic energy for variation shape 4

Figure 7 describes the results of the CFD simulation for an octagonal section, the value of turbulence kinetic energy increased in the position of 1 meter to 1.4 m on the side of the wind tunnel. The turbulence kinetic energy value of 5 simulated variations was obtained in variation 4 which has the smallest kinetic energy turbulent value.
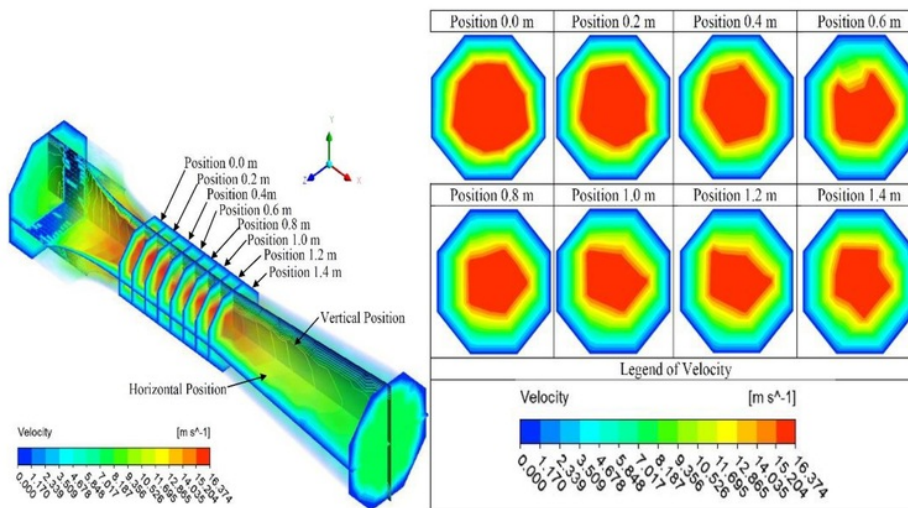

Figure 8. Velocity for variation shape 4

The fluid flow velocity in the octagonal sectional test section of figure 8 describes the maximum value of the fluid velocity flowing in the middle of the wind tunnel for all test section positions 16.374 ms^{-1}.
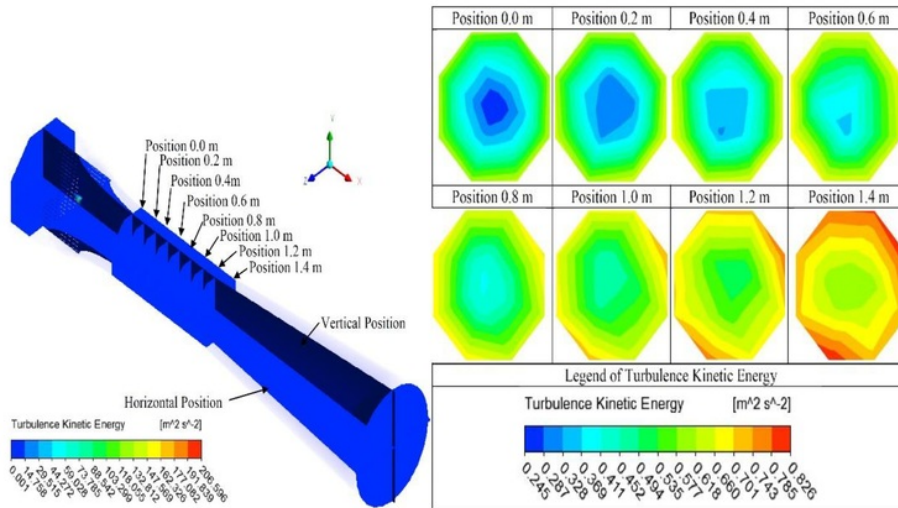
Figure 9. Turbulence kinetic energy for variation shape 5

Variation 5 in figure 9 explains the turbulence kinetic energy value for the octagonal test section. Turbulent kinetic energy value increased in the test section position 1.2 m to 1.4 m.
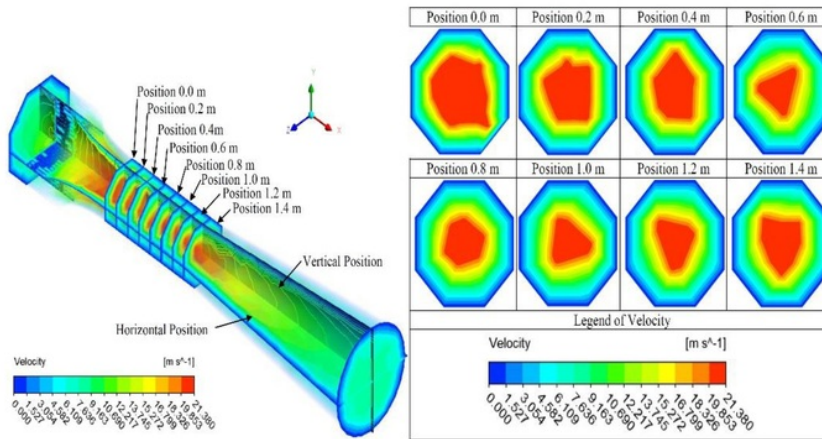

Figure 10. Velocity for variation shape 5

Figure 10 describes the fluid flow velocity in the octagonal test section and the circular section of the wind tunnel outlet. The maximum fluid flow rate is at the center of the test section.

3.2 Manual analysis
Table 3 describes the parameters that have been generated by the CFD simulation and comparison of manual analysis use the continuity equation. Parameters that have been presented from 5 variations of wind tunnel in table 3, the best variation are variation 4 because the variation has the greatest value.

Table 3. Parameters assessed from variations

Parameters assessed	Var-1	Var-2	Var-3	Var-4	Var-5
TKE (*test section*) (m^{2}s^{-2})	6.717	3.303	1.832	0.498	0.826
Velocity in *test section*	43.75	29.749	21.151	16.374	21.380
Angle *up flow* (°)	0.179	0.312	0.422	0.171	0.150
Angle *cross flow* (°)	0.167	0.256	0.241	0.202	0.533
Differential pressure (test section) (%)	0.23	0.047	0.019	0.008	0.015
Dimensions *test section* (m)	0.5	0.6	0.7	0.8	0.7
The total length of the wind tunnel (m)	6.656	6.285	5.913	5.343	5.913

4. Conclusion

From CFD simulations and manual analysis for optimal design resulted in laminar flow is an octagonal design for test section. The total length of the wind tunnel is 5.343 m which has a test section of 0.8 m with a velocity value at 16.374 ms^{-1} test section. The angle between the cross flow velocity and the speed along the wind tunnel in the test section is 0.171°. The lowest turbulence kinetic energy value produced by the wind tunnel is 0.498 m^{2}s^{-2}.

By modifying the design form on each wind tunnel module it will improve airflow quality. This is evident in the shape of the square shaped wind tunnel that the fillets provide in each corner, Produce the highest speed and low kinetic energy turbulent values.

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