Effect of applying screen and honeycomb to the flow characteristic in wind tunnel based on CFD simulation

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Abstract. In the field of wind tunnel testing, flow quality is one of considerations which determine the accuracy of data measurement. There are several aspects that affect the flow quality, such as blade design, flow conditioner application and tunnel circuit configuration (i.e. design of the corner vane, corner duct, contraction duct and etc.). Applying flow conditioner like screen or mesh and honeycomb is commonly used to improve the flow quality in the tunnel. This paper discusses about the effect of applying screen and honeycomb to the flow characteristic in a simple tunnel model. The screen was applied on the several locations at the WAD (wide angle diffuser), i.e. at the inlet, middle section, and at the outlet of the WAD. Honeycomb was applied after the last screen in the tunnel duct. In the modelization, the applied screen or mesh and honeycomb were modeled using porous media computational model and using Darcy law as a mathematical model. The CFD simulation was performed using Numeca by separating the domain into fluid domain section (for the tunnel section) and porous media domain (for the screen and honeycomb section). Unstructured mesh type, generated by Hexpress, was used on the tunnel computational domain. The results indicate the reduction of flow separation, hence more uniform flow in the tunnel, by applying screen or mesh at the WAD and by applying honeycomb in the chamber.

1. Introduction

Screen or mesh is commonly used in the field of wind tunnel to solve certain flow problems such as the turbulence intensity and flow recirculation. Wind tunnel with WAD (Wide Angle Diffuser) has usually problem with the flow quality due to the disturbance that occurs when the flow goes through to the WAD and run into separation. To overcome this problem there are several methods which can be applied, for example by applying splitter in the WAD section or applying screen or mesh of which one of the drawbacks is the increase in pressure loss.

Referring to previous studies of perforated plate, screen or mesh it has been shown, for example, according to Charles L. Wharton, screen or mesh can be applied in the wind tunnel to prevent flow separation at WAD [1]. It is also common to use screen together with honeycomb as flow conditioner according to Louis Cattafesta [2]. Tensioned screens are placed in the settling chamber to break up the larger-scale turbulent eddies into a number of small eddies. The purpose of this study is to better predict the screen or mesh and honeycomb effect on the flow characteristic at the wind tunnel wide angle diffuser (WAD). This kind of prediction is helpful in wind tunnel manufacturing when a WAD is needed in a circuit. In this study the computational model consists of 3 components, i.e. propeller, diffuser (including WAD) and a chamber. Using this kind of model, we can study the effect of honey
comb and mesh to the angularity (due to swirl behind propeller) and flow separation (at the WAD). For modelling the screen in the computational simulation, porous media model was used. This model is provided in Numeca based on Numeca user guide [5] of which the pressure drop can be calculated using different laws alternatively, such as Darcy law, Ergun Law, Integral Law. In the porous media relation there are several variables that influence the pressure drop and resistance of the grid/screen/mesh. Ideaclck concluded that the resistance of a perforated plate (similar with grid/mesh/screen) is correlated to the plate/grid porosity, Reynolds number and plate/grid thickness (t) [3]. Another study that was conducted by Katarina Nilsson discussed about the effect on porosity and plate thickness which can affect the pressure drop [4].

2. Method of analysis

The method of analysis which is used in this study consists of analytic method and numerical method. The analytical method is discussed later. It contains several equations that explain the relation between velocity, pressure, pressure loss, etc. The numerical method use Numeca software as CFD (Computational Fluid Dynamic) to simulate the flow and to predict the effect of screen/mesh or honeycomb application. In this study there are several cases that were simulated and analyzed as summarized in the following table below.

| Cases | Screen Type | Number  | Honeycomb |
|-------|-------------|---------|-----------|
| 1     | w/o         | w/o     | w/o       |
| 2     | A           | 3       | w/o       |
| 3     | B           | 3       | w/o       |
| 4     | C           | 3       | w/o       |
| 5     | D           | 3       | w/o       |
| 6     | C           | 1       | w/o       |
| 7     | C           | 2       | w/o       |
| 8     | C           | 3       | 1         |

*Screen model A, B, C, and D is discussed in the table below.

Table 2 summarizes the screen/mesh and honeycomb type which were used in this study, consisting of four different screen porosity between 71% and 47%.

| Screen/Mesh Type | Porosity (%) |
|-----------------|--------------|
| Screen A        | 71           |
| Screen B        | 63           |
| Screen C        | 57           |
| Screen D        | 47           |
| Honeycomb       | 80           |

2.1. Porous media

To make a computation model of the screen and honeycomb, a porous media model is generated. The model can representing the actual orifice at screen and honeycomb that difficult to be meshed in actual geometry model. As defined in NUMECA documentation that a porous medium is a solid permeated by an interconnected network of pores filled with a fluid. Usually both the solid matrix and the pore network are assumed to be continuous, so as to form two interpenetrating continua such as in
a sponge. Many natural substances such as rocks and soils, and man-made materials such as foams and ceramics can be considered as porous media. When simulating the flow in porous medium the user has to use a porous media model because the geometry is too complex to resolve with a grid [10].

2.2. Analytical method to modelize screen/mesh by porous media

The analytical method was done based on the pressure equation and relation as shown in the equation (1) to (6). Meanwhile the pressure drop is calculated based on screen specification such as porosity, wire diameter—which is assumed to be similar to the thickness of the screen/mesh—and diameter of the orifice; also velocity through the screen. The equation to calculate pressure drop through the screen is derived as follows [3],

\[
\Delta P = 0.5 \rho v^2 K_i \tag{1}
\]

\[
K_i = \frac{K_f}{\phi^2 + \varepsilon K} \tag{2}
\]

\(K_f\) is function of Re and \(\phi\). For high Re (Re > 200,000) \(K_f\) is equal to zero. Therefore, for high Re, the equation becomes

\[
K_i = \varepsilon K \tag{3}
\]

The value of the constant \(\varepsilon\) in the high Re is equal to 0.98

\[
K = \left( K_0 + \frac{\lambda t}{d_h} \right) / \phi^2 \tag{4}
\]

where \(\lambda\) is friction factor which for high Re it can be assumed to be close to zero, therefore equation (4) becomes

\[
K = K_0 / \phi^2 \tag{5}
\]

\[
K_0 = (0.5 + \tau(1 - \phi)^0.5(1 - \phi) + (1 - \phi)^2 \tag{6}
\]

where \(\tau\) is function of \(t/d\) as shown in [3] and \(\phi\) is porosity.

As previously mentioned, this study analysed the effect of applying screen in the WAD at the three differences locations, i.e. at inlet, at middle section and at the outlet of the WAD. Based on equation (1), pressure drop is function of velocity therefore the pressure drop for each section WAD are different.

2.3. Numerical method

The numerical method, as previously discussed, is based on CFD (Computational Fluid Dynamics) with steps as the ones in the standard CFD procedure. It started with making computational geometry model, then mesh generation, followed by solving the Navier-Stokes equations and then post processing. In the process of building computational geometry model using CAD software (for example CATIA or Solid Works), the tunnel or duct model was separated into several sections, consisting of fluid block section, porous media section and rotating domain section. Fluid block section is the modeling of the fluid flow contained in the tunnel/duct with certain boundary conditions, the porous media section represents the screen/mesh by applying the Darcy law based on pressure loss
equation, the last section is rotating domain which modeled the rotation of the model blade.

3. Simulation modeling

3.1. Computational geometry model
The geometry of the duct/tunnel with several parts of domain are depicted in the figure 1 below. As described previously, the computational model contains fluid block domain, porous media block domain which represent the screen/mesh and honeycomb; and rotating domain which models the rotation from the fan blade.

![Computational model of the duct/tunnel](image1)

3.2. Meshing
The meshing that was applied on the computational model uses structured mesh type and unstructured mesh type (cartesian mesh). The structured mesh type was applied in the rotating domain and the unstructured mesh was applied on the stationary parts, on the tunnel, screen, and the honeycomb. The rotating domain was meshed with Autogrid-5, a turbomachinery platform and a structured mesh generator with good quality of mesh result. The mesh that was used in the study is depicted in figure 3 below.

![Applied mesh on the rotating domain](image2)
3.3. Boundary conditions

The computational simulation started with the generation of computational domain in which the flow properties such as velocity, pressure and temperature would be calculated. The domain was defined with some boundaries such as inlet, outlet, connecting domain and porous media domain as shown in figure 4. The boundary conditions that were applied in the pre-setting of the simulation steps were condition on the inlet, wall and outlet. For the inlet we used mass flow and input RPM to define the rotational speed of the model blade; for the wall we used default setting of the wall boundary conditions and for the outlet we used static pressure as input value. The Darcy law was applied in the porous media domain setting. As previously stated, in this simulation the screen are modelled as porous media. To set input for porous media options in the NUMECA software, we must define the Value K’, where for constant value of K’, K’ is defined as the following equation (defined as in the NUMECA user guide [5]):

\[ \nabla P_{pm} = -K' \vec{v} \]  

(7)

To accommodate the screen thickness, the equation to determine value of K’ is modified to be

\[ K' = \frac{\nabla P_{pm}}{v \cdot t} \]  

(8)

where \( t \) is the thickness of the screen model, and \( v \) is the flow velocity that is perpendicular to the screen area. The location of the boundary conditions that were applied in the computational domain is depicted in figure 4 below.

Figure 3. Applied mesh on the duct/tunnel computational domain.
3.4. Numerical model
The equation that was used in the simulation is turbulent Navier-Stokes with K-epsilon (extended wall function) turbulence model. The number of mesh that was applied on the computational domain geometry was automatically defined by Numeca software. The type of the simulation is steady simulation and optional model of porous media was chosen. The porous media was used to simulate the screen/mesh. It was then applied at the domain where the screen/mesh was located.

3.5. Convergence of the simulation
The criteria of convergence which were used in the simulation were residual growth of mass and momentum as shown in figure 5. The residual is one of the most fundamental measures of an iterative solution of convergence, as it directly quantifies the error in the solution of the system equation. In a CFD analysis, the residual measures the local imbalance of a conserved variable in each control volume. For complicated problems, however, it is not always possible to achieve residual levels as low as -6 (global residual scale in NUMECA). However, if the global residual curve cannot reach a certain low level, the convergence of the simulation still can be assessed by monitoring the integrated quantities, such as force, drag, mass flow or average temperature. The simulation is convergence when the integrated quantities value does not fluctuate much anymore. Figure 3 shows the convergence history of integrated quantities that is represented by mass flow.
4. Simulation result and discussion
This section discusses the results of the simulation of each case, starts from case 1 to case 8. Each case is explained briefly with several visualisation like velocity vector and several contours.

4.1. Simulation without screen/mesh and honeycomb applied with fan blade on
This section discusses about the flow characteristic when the fluid flows through to the tunnel/duct without screen/mesh treatment. The flow characteristic of the flow in the tunnel/duct is depicted in figure 6 below.

Figure 6. Streamline/flowpath in the tunnel without any screen and honeycomb applied.

Figure 6 shows that the flow runs into massive separation when it passes the WAD. This could be explained by the fact that the diffuser opening is too wide that it provokes separation. The recirculation flow caused by the separation is shown by the irregular flow paths/streamline.

4.2. The effect of the screen/mesh porosity
In table 3 below the comparison from each screen to the ability in reducing flow separation at the WAD section is shown.

Table 3. Comparison of streamline/flow path of each tunnel/duct configuration.

| Screen Type | Simulation Result |
|-------------|-------------------|
| A (Porosity 71%) | ![Image](image1.png) |
| B (Porosity 63%) | ![Image](image2.png) |
| C (Porosity 57%) | ![Image](image3.png) |
Based on the simulation result that are shown in the table 3, it can be deducted that increasing screen/mesh porosity reduces the flow separation at the WAD (Wide Angle Diffuser) section. There is significant effect when the screen porosity is changed from porosity of 71% to porosity of 63%, massive separation that occur at the WAD section before, significantly thinned off by changing the screen/mesh porosity. This phenomena indicates that applying screen/mesh is useful to reduce the flow separation.

4.3. The effect of the number of screen/mesh
In this section the effect of number of screens to the ability in reducing the flow separation phenomena at the WAD section is assessed. Screen/mesh which is used in this section is screen/mesh of type C (with 57% porosity). Table 4 here below shows that separation and recirculation flow are reduced progressively by increasing screen/mesh number. Initially, with one screen/mesh the flow separation is still massive. Then by adding another screen/mesh which was applied in the duct, the separation become less massive. With three screen applied in tunnel/duct the separation seems to completely disappear especially after screen number 3.

Table 4. Comparison of streamline/flowpath of each configuration by varying the screen/mesh number.

| Screen Type       | Simulation Result |
|-------------------|-------------------|
| 1 Screen Applied  | ![Image](image1.png) |
| 2 Screen Applied  | ![Image](image2.png) |
As previously discussed, based on the simulation result that is presented in the table 4, the effect of the addition of screen’s number has similar effect with increasing screen/mesh density (lowering the porosity number). At the one screen mesh activated case, there is still occur massive recirculating flow at the WAD. With increasing active number of screen/mesh, the recirculating flow become thinned off until it almost disappear when the three screens are all activated.

4.4. The effect of applying honeycomb
In this section the effect of adding honeycomb in the tunnel/duct to the flow characteristic is discussed. The table 5 and table 6 here below depict the flow using the streamlines in the first figures and velocity vector distribution in the second. From the simulation result in table 5 it seems there is no significant difference of the stream line/flow path in the tunnel from the two configurations.

Table 5. Comparison of streamline/flow path from configuration with and without honeycomb.

| Screen Type          | Simulation Result |
|----------------------|-------------------|
| Without Honeycomb    | ![Simulation](image1) |
| With Honeycomb       | ![Simulation](image2) |

However from the figures in table 6 below, which show the distribution of velocity vector at the
downstream section after honeycomb, we can notice the difference of the velocity vector distribution. The tunnel/duct with honeycomb has more uniform velocity vector distribution than the one without it.

**Table 6.** Comparison of velocity vector distribution of tunnel/duct with and without honeycomb configuration.

| Screen Type             | Simulation Result |
|------------------------|-------------------|
| Without Honeycomb      | ![NUMECA](image1)  |
| With Honeycomb         | ![NUMECA](image2) |

5. Conclusions
In this study the effect of screen/mesh and honeycomb that were applied in the tunnel/duct with fan on condition was assessed. First, it can be concluded that the screen/mesh can prevent the flow separation at the WAD section. The ability to reduce flow separation increases with the porosity of the screen, though this increase of porosity causes the pressure loss due to the increase of the number of the screen itself. In the study of honeycomb effect it is shown that by applying honeycomb in the tunnel/duct configuration we can obtain more uniform flow. The compromise between separation area and pressure loss must be studied and the best solution will depend on the configuration of the tunnel. For this example of configuration, it is found that the best one was using three screens with 57% porosity (screen type C) at the WAD section and applying honeycomb after the WAD’s last screen.

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