The influence of chamfering and corner radiusing on the discharge coefficient of rotating axial orifices

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Abstract. The effects of chamfering and corner radiusing on the discharge coefficient of rotating axial orifices are presented in this paper. Both experimental and CFD results show that chamfering and corner radiusing improve the discharge coefficient of rotating orifices. For non-inclined rotating orifices, the discharge coefficient reduces with increasing speed, but chamfered and radiused orifices manage to have higher discharge coefficient (Cₐ) than the straight edge orifices. Comparing between chamfering and corner radiusing, the radiused corner orifice has the highest Cₐ at every rotational speed. This is because the inlet radius helps guiding the flow into the orifice and avoiding flow separation at the inlet.

1. Introduction
The characteristic of the flow through a set of rotating orifices for particular conditions is quantified in terms of a discharge coefficient which is the ratio of the actual flow divided by the flow for the ideal case.

\[ C_d = \frac{\dot{m}_{\text{actual}}}{\dot{m}_{\text{ideal}}} \]  (1)

The actual flow can be measured experimentally whereas the ideal flow is calculated according to equations derived by analysis according to stated assumptions. If the discharge coefficient is known for a particular geometry, shaft speed and flow boundary conditions such as fluid properties and pressure, the mass flow through the orifices can be calculated.

The earliest study on rotating orifices was by Meyfarth and Shine [1]. A disc with several holes drilled in it was mounted in front of a glass window. It was then placed in the exhaust stream of a J-75 turbojet engine and it was found that the glass temperature was significantly reduced. Wittig et al. [2] used the discharge coefficient derived from energy conservation, entropy and ideal gas relations. They conducted tests similar to Meyfarth and Shine [1], but with longer orifices. Their results showed that a
longer orifice gave a higher discharge coefficient than a shorter orifice. Maeng et al. [3] had a similar rotating axial orifice setup to Wittig et al., and varied the rotational speed from 0 to 10000 rpm. They used the discharge coefficient derived from Steady Flow Energy Equation. The discharge coefficient is written as:

\[ C_{d,\text{Maeng}} = \frac{m_{\text{normal}} \sqrt{T}}{p_i A} \left( 1 + \frac{T_m}{T} \right) \left( \frac{1}{\Pi} \right) \left( \frac{1}{\Pi + \frac{2T_m}{T}} \right) \]  

Idris (2004) [4] performed experimental and computational investigation of the discharge characteristics and behavior of rotating axial and radial orifices and highlighted that for rotating orifices, the most important parameter influencing the discharge coefficient is the angle of incidence. The highest discharge coefficient is attained when the incidence angle is bordering on zero.

2. Experimental setup
The objective of the experimental study was to gather discharge coefficient data for rotating orifices with combinations of flow and geometric parameters. Figure 1 shows the front view of the experimental rig. Chamfer is defined by the chamfer angle, \( \beta_w \), and the ratio of \( w/d \), while corner radius is represented by the ratio of \( r/d \), Figure 2.

3. CFD Modelling
A proprietary software called STAR-CD is used in the present study. The process of fine tuning and validating CFD codes and results are performed by comparing with experimental data. The algorithm used in this study to resolve the pressure-velocity linkage in the transport equation is SIMPLE while the turbulence model used is the RNG form of the \( k-\varepsilon \) for its improved resolution of separation and swirl. Figure 3 shows the variable parameters used in building the axial orifice model. To form a chamfer, a patch is first created as shown in Figure 4a. This patch is then extruded around the local coordinate to form the chamfer, Figure 4b. The chamfer is then attached to the orifice and the inlet and outlet regions to form the complete model, Figure 4c. A similar approach is used to form the corner radius, Figure 4d.
4. Results and discussion

Figure 5 shows the experimental results of discharge coefficient versus incidence angle for the present study and others. Hay and Spencer [5], and an ASME nozzle have data for stationary orifices while the present study shows results for both rotating and non-rotating cases. A straight orifice with an $L/d = 1.4$ for the present study gives a $C_d$ of 0.81 at 0 rpm and pressure ratio of 1.06, while Hay and Spencer [5] with $L/d = 1.0$ has $C_d = 0.95$ for a chamfered orifice at 30°, and $C_d = 0.88$ for a chamfered orifice at 45° and $C_d = 0.94$ for a radiused corner orifice. The pressure ratio used in their study was 1.2. For chamfered orifices, the discharge coefficient depends on the angle of the chamfer, with a 30° angle giving higher $C_d$ than the 45° angle chamfer.

Numerical simulations were carried out in STAR-CD to find the chamfer angle that can give the best $C_d$ for the range of speed from 0 rpm to 21000 rpm. The CFD results are compared with the experimental data at 30° chamfer. The highest $C_d$ can be achieved for chamfered angles from 20° to 45° for 0 rpm. When the speed is at 6000 rpm the chamfered angles from 25° to 40° can still maintain a high $C_d$ around 0.94. For speed of 12000 rpm a 40° chamfer gives the highest $C_d$ at 0.86. The CFD results indicate that a 40° chamfer gives the best $C_d$ for the speed up to 12000 rpm. For radiused orifices, the discharge coefficient can be maintained at a high value for $r/d \geq 2.0$. The CFD results confirm that radiusing the inlet allows the orifice to withstand the effect of rotation on the discharge coefficient. Figure 6 shows the CFD velocity vectors for sharp-edged, chamfered and corner radiused
at 0 rpm, 12000 rpm, and 21000 rpm. The radiused corner orifice has the highest $C_d$ at every rotational speed because the inlet radius helps to guide the flow into the orifice and avoid separation.

![Velocity vectors for sharp-edged, chamfered and corner radiused at 0 rpm, 12000 rpm, and 21000 rpm](image)

**Figure 6.** Velocity vectors for sharp-edged, chamfered and corner radiused at 0 rpm, 12000 rpm, and 21000 rpm

5. Conclusions
Both experimental and CFD results show that chamfered and radiused orifices give higher $C_d$ than the straight edge orifices. Radiused orifices, however can sustain the discharge coefficient much higher over a wider range of the incidence angle compared to sharp-edged and chamfered orifices. For chamfered orifices, the experimental results show that a 30° angle giving higher $C_d$ than the 45° angle chamfer. Simulations between 30° and 45° are carried out using CFD, and the results show that a 40° chamfer gives the best $C_d$ for the speed up to 12000 rpm. Even at 21000 rpm, it can still give a $C_d$ which is higher compared to much of the others. The CFD results for radiused orifices show that the discharge coefficient can be maintained at a high value for $r/d \geq 2.0$. Radiusing the inlet allows the orifice to withstand the effect of rotation on the discharge coefficient.

References
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