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Numerical Investigation of Pressure Losses in Axisymmetric Sudden Expansions with a Chamfer

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1. Introduction

Sudden expansions are used in a wide variety of engineering applications such as mechanical, chemical, civil, and nuclear industries. Owing to its relevance to the pump requirements for the operation of a pipeline system, the irreversible pressure drop in a sudden expansion has been studied extensively [1-4]. In this paper, the pressure losses through axisymmetric sudden expansions with a chamfer are analyzed by means of numerical simulation, with an emphasis on the effect of the Reynolds number.

2. Methods and Results

2.1 Computational Setup

In the present study, the following RANS equations are solved using a commercial code, Fluent 12.0 [5], under an assumption that the flow of a constant-property Newtonian fluid is steady, axisymmetric, incompressible, isothermal, and turbulent.

$$\frac{\partial \langle u_i \rangle}{\partial x_i} = 0 \qquad (1)$$

$$\rho \frac{\partial \langle u_i \rangle \langle u_j \rangle}{\partial x_j} = -\frac{\partial \langle p \rangle}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu \left(\frac{\partial \langle u_i \rangle}{\partial x_j} + \frac{\partial \langle u_j \rangle}{\partial x_i} \right) - \rho \langle u_i' u_j' \rangle \right] \qquad (2)$$

The simulations are carried out using a segregated solver. Pressure-velocity coupling is achieved through the SIMPLE algorithm. A second-order upwind method is employed for the discretization of the momentum and turbulent transport equations. For the Reynolds stresses in Eq. (2), the realizable *k-ε* turbulence model is used with the standard wall function, which is chosen based on additional sensitivity tests.

Figure 1 shows a schematic of the CFD model used in this study. To avoid the inlet and outlet boundary effects, the computational domain extends from $50D_0$ upstream to $70D_0$ downstream of the chamfer, where D_0 is the inlet pipe diameter. Regarding the boundary condition, a uniform velocity U_0 is specified at the inlet with a turbulence intensity of 3%. At the downstream end, a pressure outlet condition is imposed. The surfaces of the inlet and outlet ducts including the chamfered edge are treated as stationary no-slip smooth walls. The grid system consists of 76000 quadrilateral elements in total, which cluster around the expansion corner and the shear layer region with a minimum grid size of $\Delta x_{min}=\Delta r_{min}= 0.01D_0$. Also note that the maximum y^+ at the wall nearest cell is less than 100.

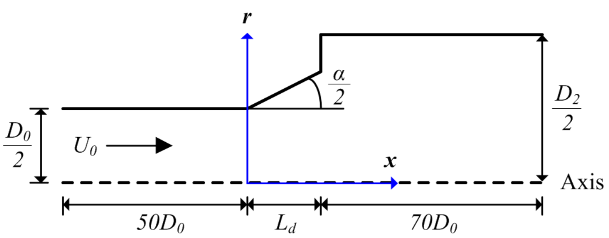

Fig. 1. Schematic diagram of computational domain [4].

2.2 Effect of Chamfered Edge on Expansion Loss

An extensive set of numerical simulations is carried out for dimensionless chamfer lengths L_d/D_0=0.02−0.5, expansion ratios $n_{ar}=(D_2/D_0)^2$=2−6, and chamfer angles α=5−45°, whereas the Reynolds number based on the bulk velocity upstream and inlet pipe diameter changes in the range of $Re=1\times10^5-8\times10^5$. Figure 2 displays the typical effect of a chamfered edge on the local loss coefficient of sudden expansions, which is defined by

$$\zeta = \frac{2(\Delta P_t - \Delta P_f)}{\rho U_0^2} \qquad (3)$$

Here, ΔP_t is the total pressure difference between the inlet and outlet planes and ΔP_f is the frictional loss on the wall obtained from the correlation of Idelchik and Fried [4,6]. In Fig. 2, it can be seen that the irreversible pressure drop due to a sudden expansion decreases with an increase in the chamfer angle. However, when the chamfer angle is greater than a certain threshold, a flow separation occurs in the chamfered surface and the local loss coefficient increases again. Concerning the impact of the chamfer length, it is shown that the local loss coefficient decreases with increasing the chamfer length. As regards the impact of the Reynolds number, it is also found that the reduction of the expansion losses with a chamfered edge is more prominent at a higher Reynolds number, while the variation of the local loss coefficient appears to be increasingly insignificant with increases in the Reynolds number.

2.3 Modeling of Local Loss Coefficient

On the basis of the foregoing numerical results, a previous correlation for the irreversible pressure drop across a sudden expansion having a slight chamfer on the edge is extended as follows

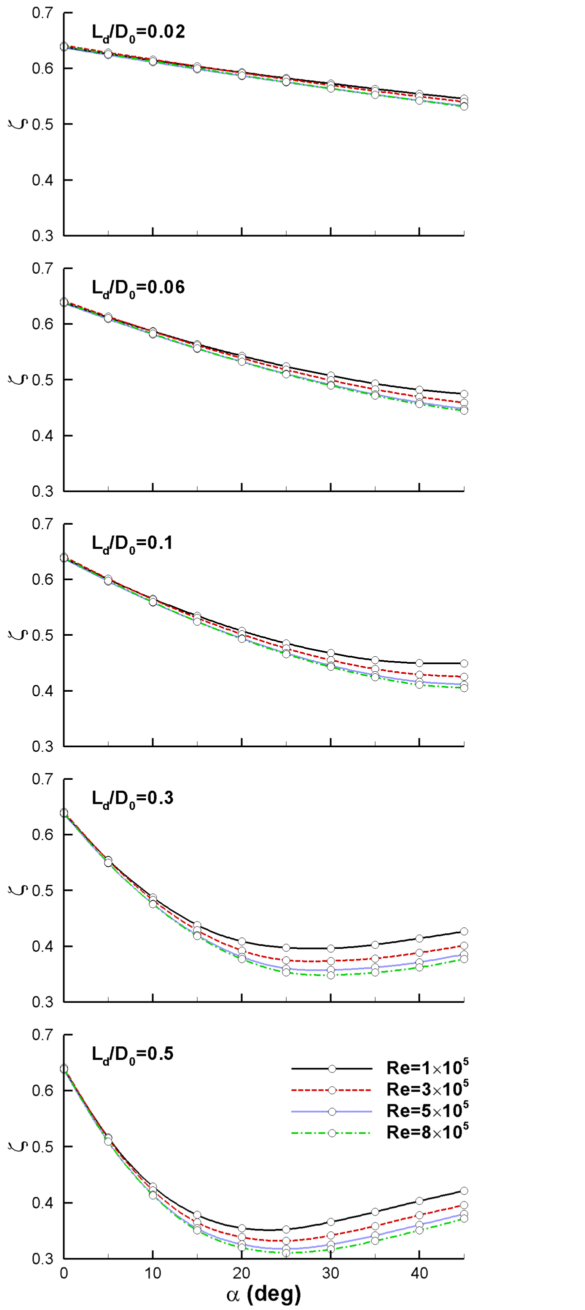

Fig. 2. Pressure loss coefficient *vs.* chamfer angle relationship at different chamfer lengths and Reynolds numbers for n_{ar}=5.

$$\zeta = \left(1 - \frac{1}{n_{ar}}\right)^2 - C_1 \zeta_c \qquad (4)$$

where ζ_c is the correction factor associated with the geometrical parameters, being expressed as a function of chamfer angle, expansion ratio, and chamfer length in reference [4]. The correction factor C_1 that takes into account the effect of Reynolds number is proposed as

$$C_1 = 0.182 \log \mathrm{Re} \qquad (5)$$

Figure 3 compares the local loss coefficient between the numerical results and the predictions based on Eqs. (4) and (5). It can be clearly seen that in all cases tested, the proposed correlation provides a good approximation of the expansion losses.

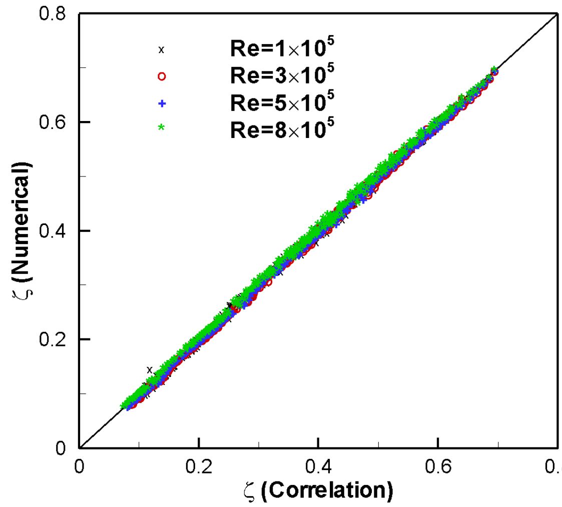

Fig. 3. Comparison of local loss coefficient between the numerical results (symbols) and the predictions based on Eq. (4) and (5) (solid lines).

3. Conclusions

In this study, we investigate numerically the turbulent flow in axisymmetric sudden expansions having a slight chamfer on the edge. With the aim of investigating the impact of Reynolds number on the expansion losses in a time-averaged sense, an extensive set of simulations is carried out. On the basis of numerical results, we also propose a general correlation to estimate the local loss coefficient in sudden expansions with a chamfer.

Acknowledgement

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