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Water Leakage through a Small Opening

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Abstract This paper presents a numerical simulation of a pressurized water leakage through a small opening into an ambient water reservoir. A modified Euler number indicating the relative importance between the forces due to pressure difference and the viscous effect was found good enough to characterize a problem of this nature. The effect of the gap aspect (H/L) ratio was investigated too. Only when the gap aspect ratio is close to unity, the gap flow is found existent in a bi-stable mode. In contrast, the uni-stable mode is possible with the right combination of modified Euler number and gap aspect ratio. More surprisingly, there exists a threshold aspect ratio approximately unity based on this work. Below the threshold aspect ratio, the maximum velocity is only a function of the modified Euler number. However, beyond the threshold aspect ratio, the maximum velocity increases with the gap aspect ratio and the modified Euler number.

Keywords Leakage Flow, Modified Euler Number, Gap Aspect Ratio, Pressure Gradient

1. Introduction

The flow behind a gap between two side-by-side bluff bodies has long been studied by Bearman and Wadcock[1], Roshko et al.[2], Zdravkovich[3], Hayashi et al.[4], Kim and Durbin[5] and Miau et al.[6]. If the gap is very small, the flow after the gap demonstrates a bi-stable characteristic. In other words, the flow will stably deflect to either side of the bluff bodies. As the gap increases, the flow goes through a transition from the bi-stable to a uni-stable characteristic. In other words, the steady flow will not deflect to either side of the bluff bodies if the gap is wide enough or, more precisely, the uni-stable characteristic is attained. In the transition, the flow was found flip-flopping between the two bluff bodies in a random manner[5-6].

In general, the studies involving this subject were carried out on either cylindrical shapes or flat plates. As one of the pioneering work, Bearman and Wadcock[1] experimentally measured the pressures on two side-by-side circular cylinders at a Reynolds number of 2.5×10^4. Later, Roshko et al.[2] also carried out a similar experiment by measuring the pressure distribution on two triangular cylinders but at a Reynolds number of approximately 2.0×10^4. Both Bearman and Wadcock[1] and Roshko et al.[2] confirmed that the pressure measurements as well as drag coefficients fluctuate between two extreme values when the gap ratio is between 0.1 and 1.0. The gap ratio in these cases was defined as the gap width between the cylinders to the diameter of the cylinders. Years later, Kim and Durbin[5] showed the possibility of controlling the intensity of the flip-flopping flow at a Reynolds number of 3.5×10^3 and a gap ratio of 0.75 using a splitter plate along the centreline of the gap or acoustic excitations. For flow through the gap between two side-by-side flat plates, Hayashi et al.[4] have found solid evidence, based on their studies corresponding to Reynolds numbers ranging from 0.6×10^4 to 1.9×10^4 and a gap ratio of 1.75, showing that the formation of flip-flopping flow is caused by the formation of shedding vortices trailing the flat plates. For the cases involving flat plate, the definition of gap ratio is similar to the above except replacing the cylinder diameter with the plate thickness. Along the same direction, Miau et al.[6] considered the cases whose gap ratios vary from 1.50 to 1.85 and found that the frequency of flip-flopping flow is proportional to the gap ratio.

The problem of fluid seepage through the cracked walls of pressure vessels has been examined quite extensively focusing on the effect of pressure on flow rate[7-10] and the propagation of crack[11-14], but the flow field associated to the opening has not been reported.

On the other hand, Wang et al.[15] numerically investigated the patterns of leakage flow through two labyrinth seals. They found that the turbulent kinetic energy reached its maximum at the clearance of the seal. The static pressure dropped rapidly when the fluid flows through the clearance.

In the extensive studies mentioned above [1-6], the configuration considered was confined to two bluff bodies placed side-by-side. A stream of flow with a known velocity was forced through the gap in between. With this, the flow phenomena related to Reynolds number and gap ratio were examined closely. Although the possible presence of a flip-flopping flow had made this topic interesting, the authors think that these configurations considered can be extended to cover more engineering

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