# WALL EFFECT ON THE CRITICAL SPACING FOR FLOW PAST TWO TANDEM CYLINDERS

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Summary When flows past two stationary cylinders in tandem arrangement during free-stream, there is critical spacing beyond which a transition from attachment regime to co-shedding regime happens, corresponding to a sudden jump of Strouhal number. In this study, we perform the lattice Boltzmann method to investigate the wall effect on the critical spacing for flows past two tandem cylinders symmetrically placed between two parallel walls with a fixed Reynolds number at 100. Results show that such phenomena are also observed for all the present cases and as blockage ratio decreases from 1/2 to 1/16, the critical spacing first increases and then decreases. The mechanism is still not well understood and a further work is currently underway.

## INTRODUCTION

Flow pasts two tandem cylinders is one of the classical problem in fluid mechanics [1-3]. In the vortex shedding regime, a significant phenomenon observed in previous works is that there is a critical spacing beyond which a transition from attachment regime to co-shedding regime happens, corresponding to a sudden jump of Strouhal number, drag and lift forces. Based on the cylinder center-to-center spacing $S/D$ depending on the Reynolds number, a classification was given by Zdravkovich [1], for $S/D=[1,1.2-1.8]$, the free shear layers separating from the front cylinder overshoot the rear cylinder and vortices only shed in the wake of the rear cylinder.
For $S/D=[1.2-1.8,3.4-3.8]$, the free shear layers reattach on the upstream side of the rear cylinder, vortices also only shed behind the rear cylinder. When $S/D$ is increased beyond a critical value, a co-shedding regime with a coupled frequency appears.
In the other hand, previous works indicated that when flows past a cylinder placed between two parallel walls, the walls have a significant effect to the flow structure. For the vortex shedding regime, as the cylinder is placed near the centerline, a pattern similar to the Von Karman street with opposite final vortex position is observed. When the cylinder approaches one wall, only a single row of same-sign vortices sheds at the other side of the cylinder far away the wall. Chen [4] studied flow past a cylinder placed symmetrically between two parallel planes and results showed that the blockage ratio had a complicated effect to the critical Reynolds number where symmetrical steady flow break. As the blockage ratio increased from 0 to 0.7, the critical Reynolds number first increased and then decreased. In this work, our interest is to investigate the effect of two parallel walls to the critical spacing for flows past two stationary tandem cylinders. To the best of our knowledge, there is no literature dealing with such a problem.

## PROBLEM STATEMENT AND NUMERICAL METHOD

Figure1 presents the schematic diagram of flow past two tandem cylinders placed centrally inside a channel. $D$ is the cylinder diameter, $S$ is the center-to-center spacing of the cylinders and $H$ is the width of the channel. The inlet flow velocity is given by a prescribed parabolic profile: $U_{in}=U[1-4(y/H)^2]$, where $U$ is the inlet centerline velocity. Such a system is governed by three main parameters: the Reynolds number $\mathrm{Re}=UD/\nu$, nondimensional spacing $S/D$ and blockage ratio $\beta=D/H$.

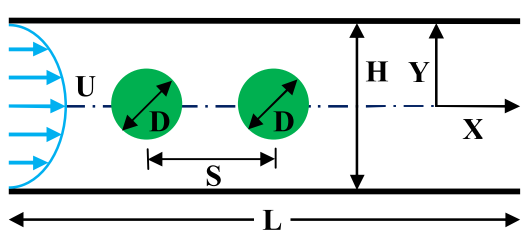


Fig.1. Schematic diagram of the flow.

In this paper, we fix Re=100 to study the critical spacing $S_C/D$ versus blockage ratio $\beta=[1/16,1/2]$. A 2-dimentional-9-speed lattice Boltzmann model [5] with an extrapolation method [6] for solid boundary is adopted in present simulations. For all the present simulations, the channel length is $L=60D$ and the upstream cylinder is placed at $20D$ downstream of the inlet boundary. The cylinder diameter is occupied by 24 lattices and the inlet dimensionless free-stream velocity is $U=0.1$. To our experience, such a scheme could keep enough accuracy.

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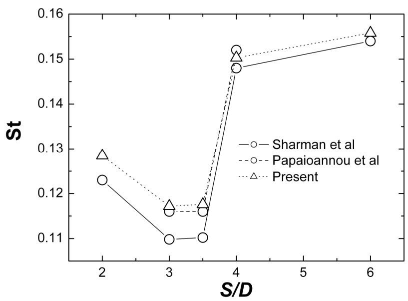
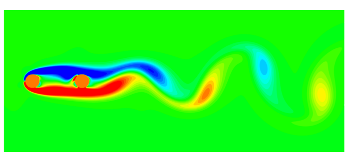
## RESULTS

Figure 2(a) shows the computed Strouhal number versus the spacing for flows past two tandem cylinders during free-stream at Re=100. As a comparison, we also give the results of Sharman et al [2] and Papaioannou et al [3]. The previous and present results agree well with each other and all with a critical spacing $S_C/D$ = [3.5, 4] where a transition from reattachment regime to the co-shedding happen, as shown in Figs.2. (b, c). Such a jump phenomenon is the main attention of this paper and the present study focus on the effect of the blockage ratio. Figure 3(a) shows $S_C/D$ as a function of $\beta$ for flows past two tandem cylinders between two parallel walls. In Fig.3.(a), as $\beta$ decreases, $S_C/D$ first increases until to a peak value about 4.55 at around $\beta = 1/10$ and then decreases till to $\beta = 1/16$ with a $S_C/D$ at around 4.4. As we have known, if we continue to decrease $\beta$ till to the free-stream case, which according to $\beta = 0$, $S_C/D$ arrives to an extremum between 3.5 and 4. For the present study, some cases with a $S/D$ just below the critical spacing, steady stationary states are also observed, while beyond the critical spacing, all behave the co-shedding states, e.g., Figure 3 (b, c) show the flow structures at $\beta = 1/4$. We still don't understand such a phenomenon well and a further study with a range of Re between 60 and 240 is underway to explore the mechanism behind such a complicated phenomenon.



(a)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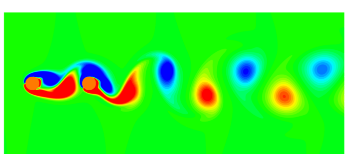
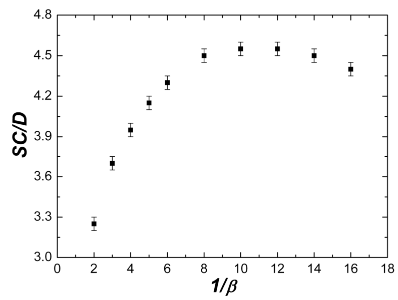
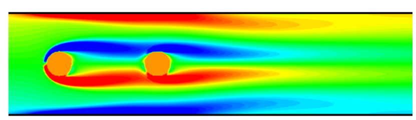
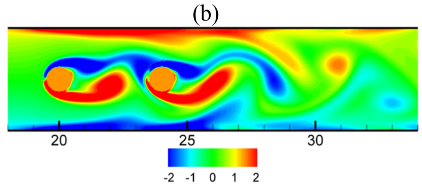

(c)

Fig.2. (a) Strouhal number as a function of spacing at Re = 100. Instantaneous vorticity contours with $S/D$ = (b) 3.5; (c) 4.0.



(a)


(b)



(c)

Fig.3. (a) Blockage ratio versus critical spacing at Re=100. Instantaneous vorticity contours for $\beta = 1/4$ with $S/D$ = (b) 3.9; (c) 4.0.

## CONCLUSIONS

We perform the lattice Boltzmann method to study flows past two tandem cylinders placed symmetrically between two parallel walls. Similar transitions to the case of free-stream are observed far all the present simulations and as the blockage ratio decreases, the critical spacing first increases and then decreases.

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