Numerical Study of the Drag Reduction and the Electronics Composites Cooling by using the Three Flat Plates

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Abstract: The objective of this research is to study the flow control allowing the reduction of the aerodynamic drag and at the same time the cooling of the electronic components. To this end, a numerical study was carried out on the effect of the length of three parallel flat plates on the control of vortex shedding behind a heated square block located in a two-dimensional channel at Reynolds number fixe (Re = 150). The numerical approach used to simulate these physical problems is the lattice Boltzmann method (LBM). The results obtained are illustrated in terms of velocity contours and isotherms. These results present a reduction of more than 67% of the drag coefficient for a critical length of the control plates (Lp = 2D). In addition, a large and regular heat exchange for the same length is observed.

1 INTRODUCTION

Nowadays, the technology of electronic components has progressed strongly. However, despite this development, the successive increase in temperature and the high vortex shedding leads to a decrease in the operating performance and sometimes to the breakdown of these electronic components (processors, high-performance servers, etc.). In order to avoid these impediments, the protection of the performance of these electronic systems and the improvement of their efficiency is the greatest challenge facing researchers and companies in the electronics industry (El Omari, Kousksou, and Le Guer 2011; Ali and Arshad 2017; De Césaro Oliveski, Krenzinger, and Vielmo 2003; Seyyedi et al. 2012; Nazari and Ramzani 2014)

(El Omari, Kousksou, and Le Guer 2011) presented a numerical study on the analysis of a passive cooling system. They employed various geometries of enclosures filled with phase change material (PCM) with enhanced thermal conductivity. The authors evaluated five geometric shapes that contained the same volume of PCM while cooling the same surface. Their calculation results show the significant effect of changing the geometry. Indeed, they found a maximum temperature difference of up to 40°C between two of the enclosures. An enclosure offset vertically from the cooled surface represented a better performance. (Seyyedi et al. 2012)applied the Boltzmann lattice method (LBM) to investigate the influence of a separator plate and an inclined square cylinder (with 45°). They used a horizontal channel filled with air with a blocking ratio (β=0.25) as study geometry. The effects of the plate and cylinder were examined on the two-dimensional unsteady laminar flow and on the heat transfer within the channel. Their numerical results found that there is an excellent position for the separator plate. This is demonstrated by a maximum value of the ratio between the Nusselt number and the drag coefficient. They also showed that there are particular points where there is a sharp jump in drag coefficient and average Nusselt number.

This research presents work aimed at controlling the flow around electronic systems to improve their performance and increase their efficiency, as well as improving the quality of heat

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transference around these systems. For this purpose, a numerical study of the flow around a heated square block controlled by three flat plates parallels located in a bi-dimensional channel was performed. The simulations were carried out by the double multiple lattice Boltzmann method. The influence of the length of the control plates on the temporal and average variation of the drag coefficient and on the heat exchange was presented.

2 CONFIGURATION DESCRIPTION AND BOUNDARY CONDITIONS

2.1 Configuration Domain and Initial Conditions

Figure 1 illustrates the geometry employed to study the flow past a heated square cylinder controlled by three control partitions placed in a horizontal bidimensional channel. The square cylinder positioned in an upstream distance Lu =6D and a downstream length sufficiently wide Ld = 31D, and a height H =11D (see Fig. 1) where the "D" represents the dimension of the square cylinder. The controlling partitions are arranged successively downstream the principal square cylinder, having the same length "Lp" and height "h=0.02D". Moreover, g designates the gap spacing between the square cylinder and partitions (see Fig. 1). The fluid entering with a dimensionless temperature $\theta_c = -0{,}5$ and the block is considered heated with a dimensionless temperature $\theta_h = 0{,}5$.

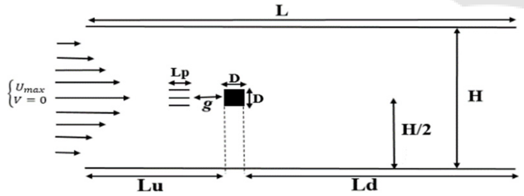


Figure 1: The structure of the computational domain.

At the channel input, the flow is created based on a parabolic velocity profile (u = 1.5 *U_{max} (1- (y/H)); v = 0), where U_{max} is the maximal entrance velocity, and y is the vertical dimension from the centerline, and u and v are the components of velocity vectors. As well as at the outlet, the parabolic velocity profile is imposed and the gradients of velocity and pressure are considered to be zero.

2.2 Boundary Conditions

In LBM, the most well-known type of boundary conditions in the literature, are the Bounce-Back boundary conditions(Bouzidi, Firdaouss, and Lallemand 2001). These conditions are used in the present work to define the solid walls of the channel. In the inlet and outlet of the channel, the flow is completely expanded with a parabolic velocity profile, so the implementation of the boundary conditions of Zou and He is the most preferred(Zou and He 1997)

The conditions suggested by (Mezrhab et al. 2010) are used to treat the heat flow boundary conditions. thus The adiabatic boundary conditions are applied for the channel walls.

3 NUMERICAL SCHEME

As already mentioned, this paper uses the LB method as the numerical approach to simulate the physical phenomenon studied in this work.

Two models are widely used for this method, the LBM a single relaxation time (BGK-SRT) scheme (Bhatnagar, Gross, and Krook 1954; Lallemand and Luo 2000) and the multiple relaxation time (MRT) scheme (Moussaoui et al. 2021; Admi, Moussaoui, and Mezrhab 2020; Benhamou et al. 2020; Moussaoui et al. 2019).

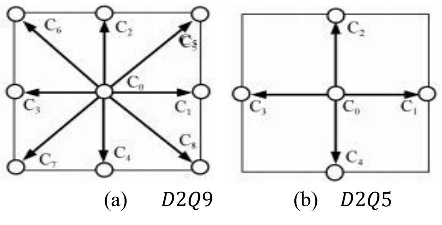
In this paper, the MRT model is used since it is more stable, precise and presents a good convergence compared to the SRT model.

3.1 The D2Q9 Model

Thanks to reasons of convergence and compatibility with the model used in thermic, the D2Q9 model was used to treat the distribution of the density of fluid particles. This model is illustrated in figure 1. For more information, see my previous work(Admi, Moussaoui, and Mezrhab 2020).

3.2 The D2Q5 Model

For reasons of compatibility and reduction of calculation time, the D2Q5 model is used to treat the thermal problem. The motion of the fluid particles, in this model (D2Q5), is carried out by the discrete velocities which are given by (Admi et al., 2020):

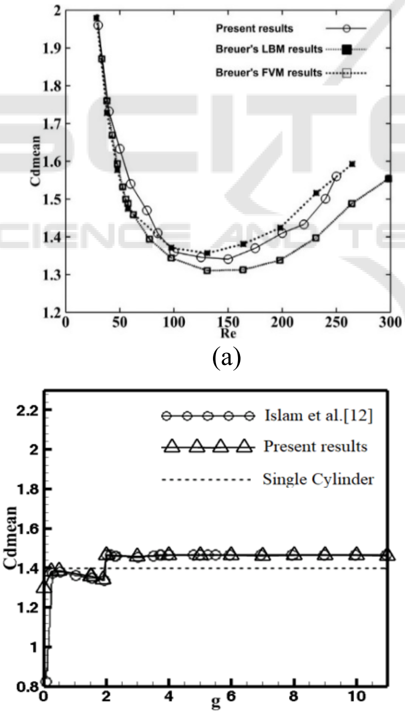


(a) $D2Q9$ (b) $D2Q5$

Figure 2: D2Q9 and D2Q5 LBM schemes.

4 CODE VALIDATION

In this work, we have two validation cases with two different problems. First, we validated our numerical code with the work of (Breuer et al. 2000) using both methods: LBM and FVM (finite volume method), where we examined the flow around a square cylinder installed inside a horizontal channel with a blocking ratio of 1/8. Fig. 3-a shows the graph showing the temporal variation of the drag coefficient as a function of Reynolds. An agreement existing between our results and those of Breuer is observed. The small differences between the two results may be due to the mesh size used. Next, we validated our numerical results with those found numerically by (Islam et al. 2015) or experimentally by (Okajima A 1982) for a flow around a square obstacle controlled by a single flat plate (fig. 3-b). Figure 4 shows the variation of the mean value of the drag coefficient as a function of the spacing between the square block and the control plate. A good correspondence is noted between our results and the reference results.



(a)

(b)

Figure 3: Comparison of our results for the average drag coefficient with previous works for a single obstacle: (a) without control partition; (b) with control partition.

5 NUMERICAL RESULTS AND DISCUSSION

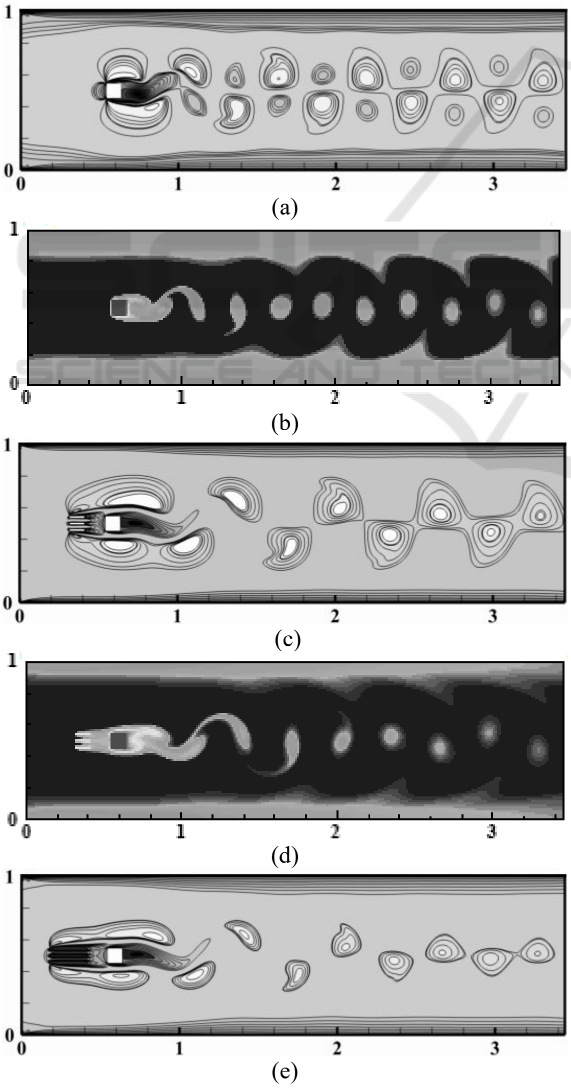
The present section presents the obtained numerical results of the effect of the length of the three flat plates on the velocity contours of the flow patterns, the isotherm contours and on the mean and time drag coefficient. To avoid the effect of the location between the plates and the block, a study was carried out to find the optimal location for which we have a maximum reduction of the drag coefficient and large and regular heat exchange. The results obtained in this study show that the optimal position of the partitions is g=1.5. In the present work, we have placed the plates at this critical distance (g = 1.5) and we have varied their lengths (1D < Lp < 5.5D).

5.1 Streamline Structures and Isotherms

Figure 5 illustrates the velocity contours (5-a,c,e,g) and isotherms (5-b,d,f,h) around the square cylinder, heated and controlled by three parallel flat plates placed horizontally upstream. In this figure (fig.5), an alternate Van Karman vortex street is seen in the wake area downstream of the square cylinder. The wake can be considered as periodically undulating in the case where the control partitions are not implemented (no control case). This undulation decreases with the increasing plate length until a critical length Lp=2.5D (Fig.5-e,f). After this critical length, the wake becomes strongly undulated (see fig. 5-g,h).

Likewise, an alternation of positive and negative vortices is observed in the uncontrolled case and in the cases where the plate length exceeds the critical length, whereas in the cases at or approaching the critical length only negative vortices are apparent. Also, the size of detached vortexes behind the square cylinder decreases with the increasing length until Lp-critical=2.5D where the vortexes are smaller in size. Then, this size increases strongly with the increase of the length of the plates.

We also observe that the number of vortexes shedding behind the square cylinder in the uncontrolled case than in the controlled cases. This is justified by the direct exposure of the frontal surface of the cylinder to the entering fluid in the uncontrolled case. Whereas in the case where the three control plates are inserted, the incoming fluid strikes the plates firstly before the block. This decreases the fluidic forces acting on the square cylinder compared to the uncontrolled case. Similarly, in the case where the plates are present, part of the front face of the cylinder is exposed directly to the incoming fluid while the other part is controlled by these three plates. Thus, in the case where Lp varies from Lp = 1D to Lp = 3D (case tested: g=1; 1.3; 1.5; 2; 2.2; 2.5; 2.7; 3) the length of the control plates is small, the fluid considers the whole (square cylinder + three partitions) as one bluffing body. For these lengths, the shear layers produced by the edges of the partitions jump up and down behind the square cylinder. This decreases the number and size of vortices released behind the square cylinder (the fluidic forces acting on the square cylinder also decrease). Whereas, in the case where the length is large (Lp > 3D), the shear layers are stuck from the bottom and top surface of the plates and then partially or completely hit the front face of the square cylinder, which again increases the size of the vortices shedding behind the square cylinder.



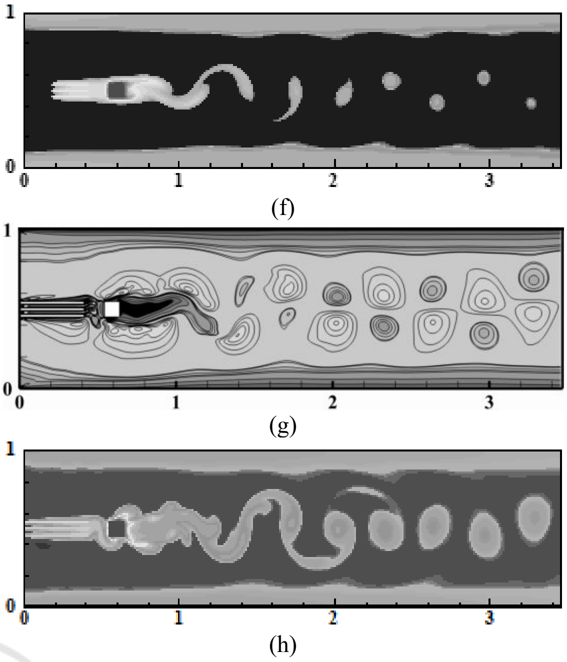
(a)

(b)

(c)

(d)

(e)



(f)

(g)

(h)

Figure 4: Velocity & Isotherms contours visualisation : Velocity contours (a, c, e, g);Isotherms contours (b, d, f, h)

5.2 Drag Coefficient

In this section, the effect of the length of the plates on the time-averaged drag force acting on the square cylinder. Table 1 gives the average values of the drag coefficient Cdmean and the length of the control plates while fixing the spacing between the partitions and the square cylinder. Figure 5 illustrates the time variation of the drag coefficient in the case with and without control plates. From this figure, it can be noted that the drag coefficient varies periodically and that the average value of the drag coefficient is $Cdmean0 = 1.1$. A comparison between Cdmean0 and the average values presented in Table 1 shows that the drag acting on the cylinder decreases significantly when the control partitions are implemented. This decrease (drag reduction) is caused by changing the flow input that hits the square cylinder. In this work, the control plates are located before the cylinder, so the cylinder will be in the wake of the plates. This will decrease the pressure forces applied in this wake area, resulting in a decrease in drag force (also, an increase in lift force).

Table1: The average drag coefficient in function of the flat plates length.

Lp	**Cdmean**	**Lp**	**Cdmean**
Without control	1.0998	2.2D	0.3905
1D	0.4831	**2.5D**	**0.3892**
1.3D	0.4453	3D	0.4078
1.5D	0.4268	4D	0.6948
2D	0.3969	5.5D	1.0384

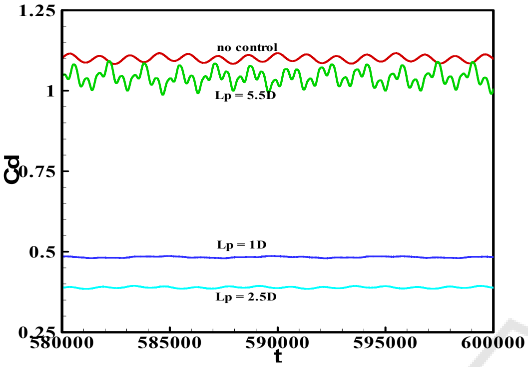


Figure 5. The temporal drag coefficient visualisation

Similarly, Table 1 shows that the highest Cdmean value appears for the uncontrolled case, then a reduction in Cdmean values is observed until it reaches a minimum in the case where the length of the plates becomes equal Lp_{cr} = 2.5. At this critical length, an effective vortex suppression was observed. After this critical length, the average drag coefficient increases again with increasing plate length. The front face of the square cylinder is partially or totally exposed to the shear layers detached by the edges of the control plates. This increases the pressure forces applied on the cylinder and consequently increases the drag force. The optimal length of the control plates (Lp=2.5) corresponds to a minimum Cdmean value and a high and even heat exchange. A maximum reduction of the average drag coefficient reaches about 64.6% for Lp=2.5D (critical length). Therefore, in the other cases (Lp varies from 1D to 3D), the incoming fluid considers the control plates and the cylinder as a single bluff body. This reduces the fluidic forces applied on the cylinder and the amplitude of the vortex shedding.

6 CONCLUSIONS

The present research presents a numerical investigation that had been performed to study the vortex suppression (drag reduction) and to study the heat transfer characteristics on a heated square cylinder placed in a horizontal 2D channel and controlled by three partitions arranged in parallel upstream of the square cylinder.

The numerical results obtained show that the drag acting on the square cylinder reduces in all the cases studied compared to the uncontrolled case. This shows the importance and the necessity of flow control. The maximum reduction of the drag is observed in the case where the length of the partitions becomes a critical length Lpcr = 2.5D. At this length, important and regular heat exchange is observed. Also, the size of the thermal vortices and the width of the Von Karman street decreases at this critical position. Therefore, for beneficial use of the control partitions, for example, in the cooling of electronic components, it is preferable to use three parallel partitions of length Lp = 2.5D placed upstream of the square cylinder at a critical distance g = 1,5.

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