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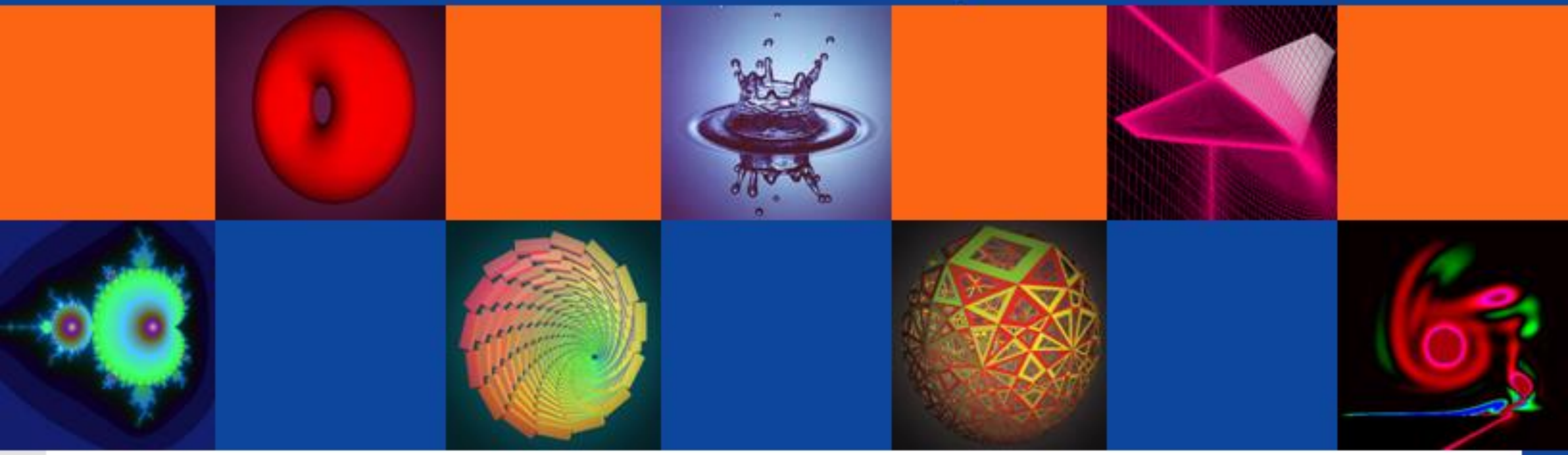

Optimization of MVG for Control of Shock Boundary Layer Interaction

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Optimization of MVG for Control of Shock Boundary Layer Interaction

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Keywords: SBLI, MVG, LES, shock, separation, optimization

Abstract

Based on the new theory of MVG to reduce separation caused by shock boundary layer interaction (SBLI), a new optimization method is presented in this paper. The key issue is to generate a proper momentum deficit zone, which can generate a strong shear layer and further strong vortex rings frequently, in front of shock. Several artificial momentum deficit zones (low speed streaks) are tested by LES and the efficiency of reduction of SBLI induced separation will be assessed.

I. Introduction

Micro vortex generator (MVG) including micro ramp and micro vane is widely used for reduction of separation caused by shock and boundary layer interaction (Lin et, al 1994; 2002; Babynski, 2009.) The mechanism why MVG can reduce flow separation is widely accepted as that the MVG can generate streamwise vortex which strongly mix the boundary layer and make the velocity profile fuller at the bottom. Therefore, the boundary layer becomes more capable to resistant the strong adverse pressure gradient caused by shocks to keep attached. **However, this is not the case.**

Li and Liu (2010a and 2010b, Figure 1) already showed the real mechanism of MVG is to generate a strong momentum deficit zone behind MVG (Figures 2 and 3.) This momentum deficit zone can generate a strong shear layer and further a chain of vortex rings due to the K-H type instability (Figures 4 & 5.) The new finding given by Li and Liu has been confirmed by Lu et al (2012) and Sun et al (2012) (see Figures 6 & 7)

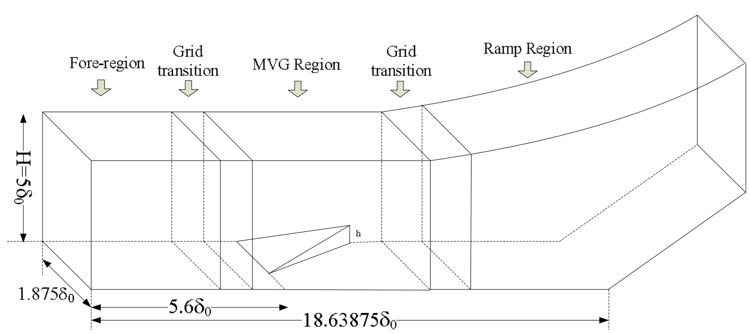


Figure 1 A sample case of MVG

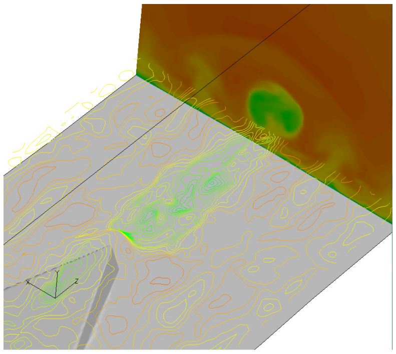


Figure 2: Momentum deficit behind MVG

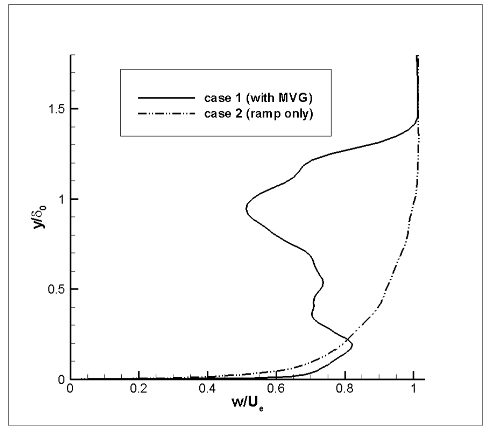


Figure 3: The distribution of the time-averaged streamwise velocity with and without MVG

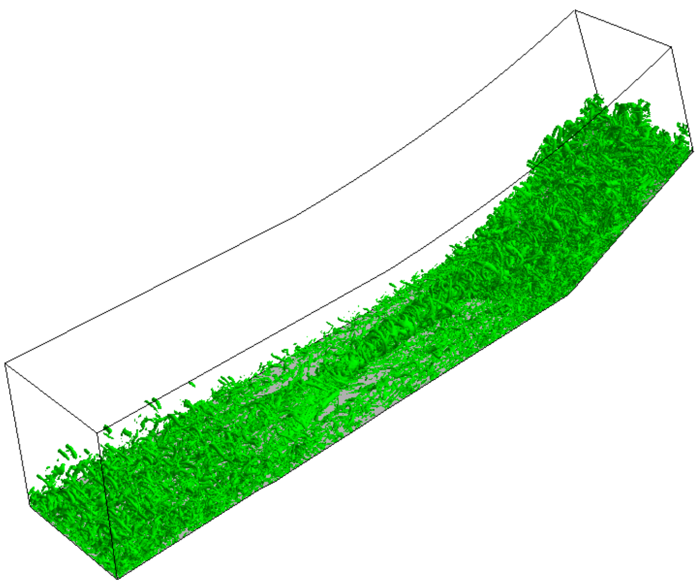


Figure 4: A chain of vortex rings generated by MVG

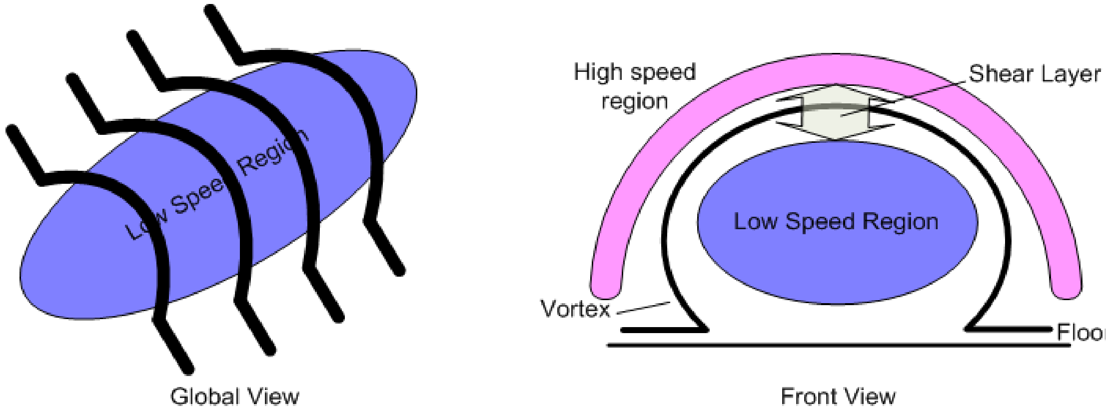
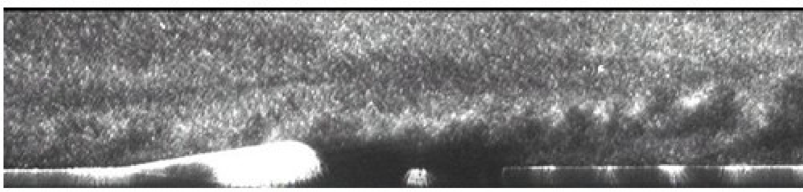
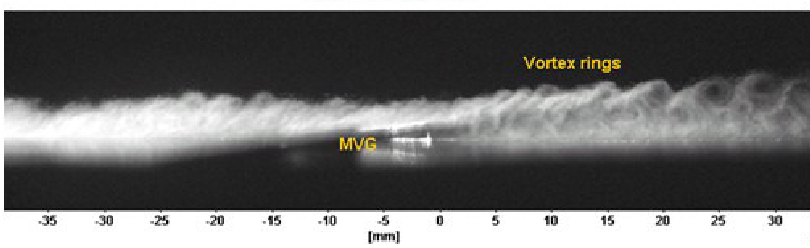


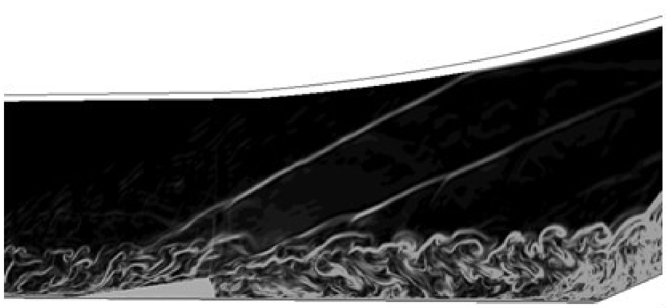
Figure 5: Sketch of vortex ring generation by shear layer with low speed streaks



a) Using PIV

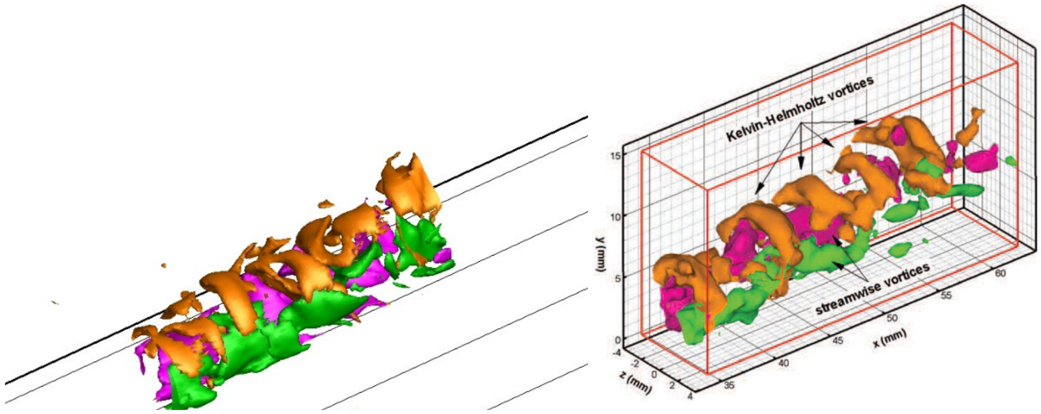


b) Using the acetone vapor



c) Contours of $|\nabla \rho|$ at the center planes by using LES

Figure 6: Comparison of LES (Li & Liu, 2010) with experiment (Lu et al, 2012)

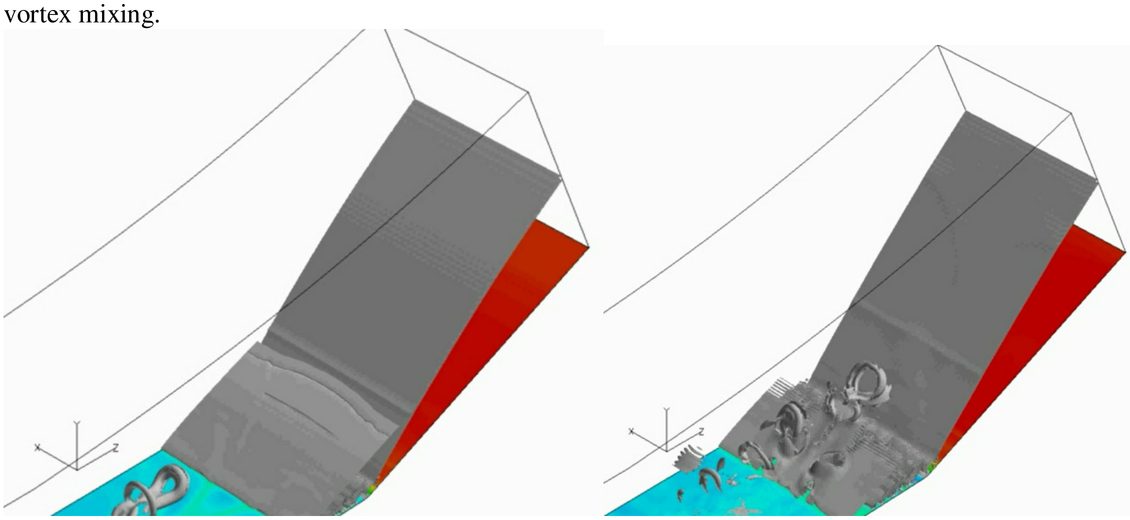


(a) LES (Li & Liu, 2010a) (b) PIV experiment (Sun et al 2012)

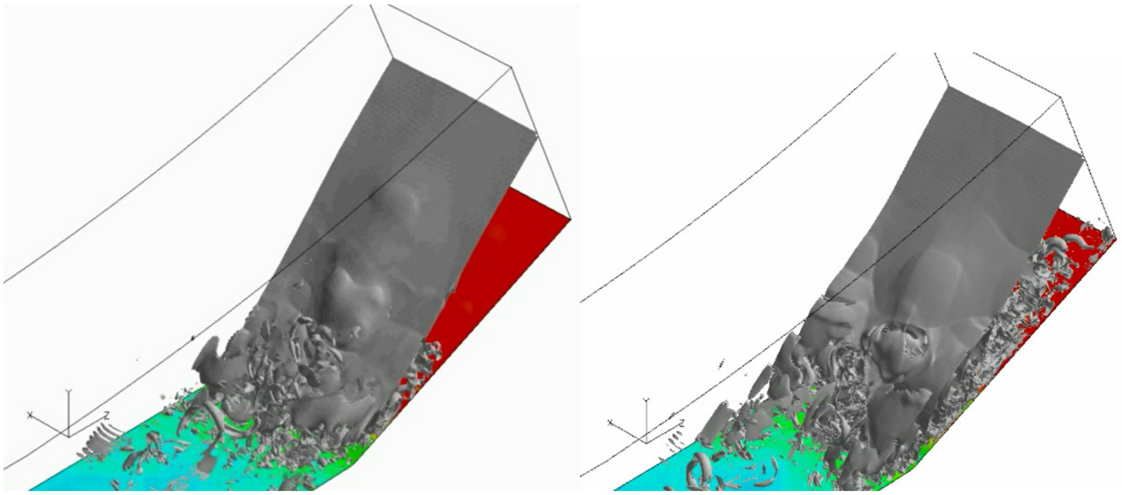
Figure 7: Comparison in distribution of Kelvin-Helmholtz vortices and streamwise vortices

II New observation of shock vortex ring interaction

These vortex rings can travel downstream and hit the shock. Due to the low pressure in the vortex center and strong rotation of the vortex rings, the shock is broken by the vortex ring and shock interaction. Figure 8 recorded the snap shots of shock vortex ring interaction at several time steps. After the shock is broken by vortex rings, the adverse pressure gradient disappears and thus the separation induced by shock boundary layer interaction will be reduced or disappear. This is the real mechanism of MVG to reduce the separation caused by SBLI, but not the streamwise vortex mixing.



(a) Ramp shock and separation shock at T1 (b) Separation shock is broken by vortex rings at T2



(c) Separation shock disappears at T3 (d) Both separation shock and ramp shock are broken at T4

Figure 8: Vortex ring and shock interaction visualized by the iso-surface of $|\nabla p|$

III Important conclusion

The current optimization of MVG is still based on the test of changes in the length, height, shape and location of MVG. These optimization tries are still empirical and hard to achieve the best design. Based on the new theory given by Li and Liu (2010a), we develop new ways to optimize the micro vortex generator. A good MVG or any designed devices should be able to produce a strong momentum deficit zone and further sharp shear layer which can generate strong vortex rings more frequently. In order to reduce or remove the separation, the vortex ring travel routine must be lower, near the separation zone, to break the separation shock which generates the adverse pressure and cause the boundary layer separation.

IV Future work

LES will be conducted for these devices. Since this is a computation, we can artificially set the momentum deficit zone without MVG or other barriers. An optimization momentum zone will be found, which can generate strong vortex rings more frequently. Based on the optimization of the momentum deficit zone, we can modify the MVG or other devices which can generate the low speed streak and further vortex rings which are stronger and more frequent. These will give the flow control engineer a fresh idea how to control SBLI and how to reduce the flow separation caused by SBLI and other flow separation control technology. This will also give a fresh idea how to optimize MVG and other flow control devices. A full report on this technology of optimization of MVG and other devices will be reported in the final AIAA paper.

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