LES Study on Vortex Ring-Shock Interaction Behind MVG

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1. Introduction

1.1 Short review of MVG

Shock-boundary layer interaction (SBLI) is a kind of problem which is frequently met in supersonic engine inlet flow and external flow. The interactions usually decrease the total pressure recovery, degenerate the shape factor of the supersonic boundary layer, and result in flow separation. Recently, in order to improve the circumstances, an inner boundary layer control device called as micro vortex generator (MVG) is developed as a new control device, which has achieved the reduced drag with relatively physical simplicity (Babinsky et al 2009; Lee et al, 2010; Ghosh et al 2010; Li et al 2010; Sun et al 2011; Saad et al 2011). It is considered to be a hopeful substitution for bleeding control. In contrast to the conventional counterpart, the microramp vortex generator has the smaller size (approximately the height 20-40% of the boundary layer), longer streamwise distance for the vortices to remain in the boundary layer, and therefore better efficiency of the momentum exchange.

1.2 Shock-vortex ring interaction

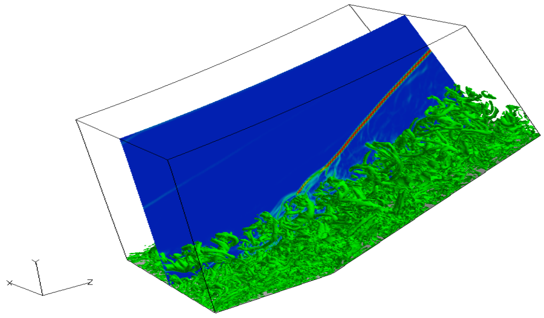
Vortex-shock wave interaction has been studied for a while. Main concerned issues in this topic are: a) the deformation of the shock wave; b) the multistage features of the interaction caused by the vortex interaction with the primary shock and the reflection shocks, etc; c) the acoustic characteristics, which includes near- and far-field of acoustic, the dipole and quadruple acoustic pressure structure, etc.

The vortex rings-shock interaction of the MVG controlled ramp flow is a new topic and different from the above standard ones. The differences include: a) the interaction is a more complicated 3-D one than the 2-D counterpart, which happens between 3-D vortex rings and the oblique shock wave; b) the interaction happens within or close to the boundary layer and the separation region, where other flow structures exist like vortices with small scale besides the shock wave; c) the interaction is a continuous one; d) besides the rings, components of the primary vortices still exist and make the interaction more complicated.

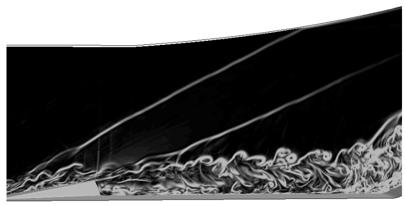
1.3 LES validation

In this study, we investigate the interaction between vortex rings and the oblique shocks by the MVG controlled ramp flow at M=2.5 and Re_θ=5760. The trailing edge declining angle of the MVG is 70° in computation. An implicit large eddy simulation method is used by solving the unfiltered form of the Navier-Stokes equations with the 5th order Bandwidth-optimized *WENO* scheme. The LES results given by Li and Liu (2010, Figure 1 and Figure 3) are very well validated by comparison with experiment work by Lu et al (2010, Figure 2) and Sun et al

(2011, Figure 4).

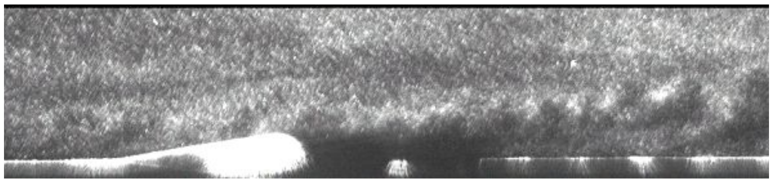


(a) Λ2 vortex and shocks plane

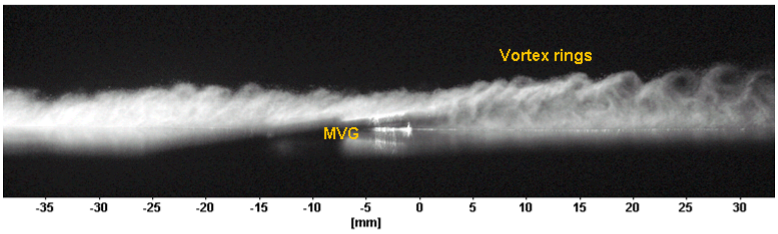


(b) numerical shilieren at center

Fig.1 Shock-vortex interaction (Li & Liu, 2010)



a) Using PIV



b) Using the acetone vapor

Fig.2 The laser-sheet flash image at the center plane (Lu et al 2010)

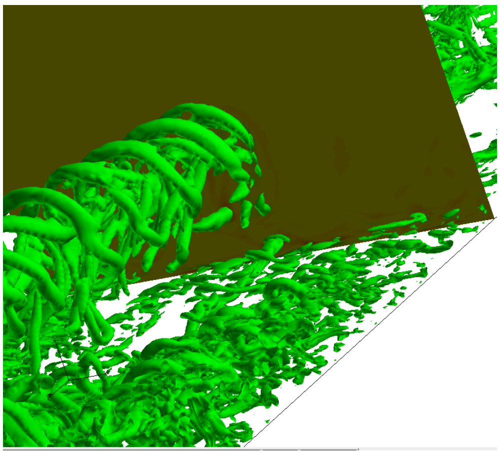


Fig. 3 K-H rings behind MVG by LES (Li & Liu 2010)

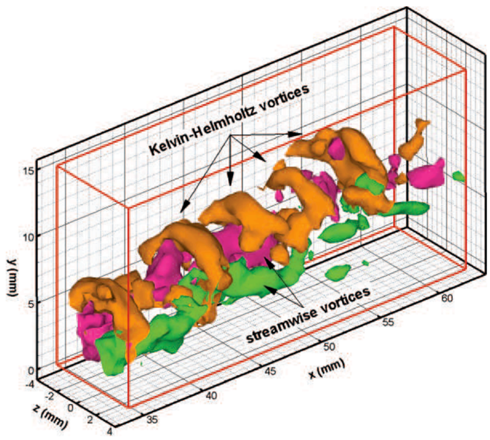


Fig. 4 K-H rings bihind MVG by Experiment (Sun et al 2011)

2 Problem Statement

Figure 5 shows the numerical shilieren in the center planes and Figure 6 provides the 3-D graphics of the shock-vortex ring interaction by the iso-surface of $|\nabla p|$

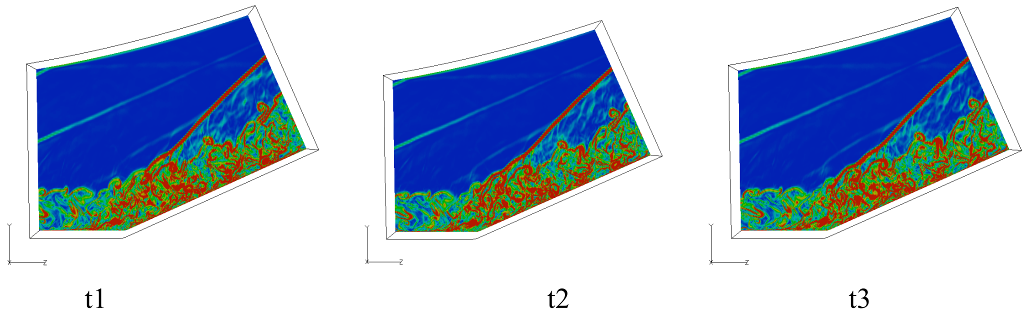


Figure 5: Contours of $|\nabla \rho|$ at three successive moments at the center planes

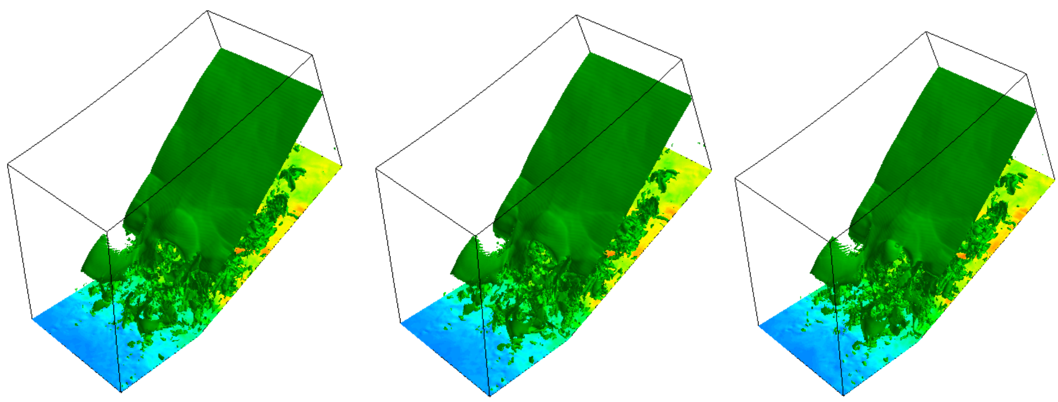


Figure 6: The 3-D shape of the distorted shock wave by the iso-surface of $|\nabla p|$

3 Conclusion and Future Work

From the figures, the following features can be observed:

1) In Fig. 5 and Fig. 6, it clearly demonstrates that there are at least two layers of shock wave structures after the ramp corner: upper one is the original but weak separation shock; the other one is a stronger interacting shock wave caused by the vortex rings. These two layers of shocks will merge into one shock wave afterwards, which are the oblique shock caused by ramp. There are also at least two types of shock wave reflection in the spanwise view, i.e., the regular reflection and the non-regular reflection. For the non-regular reflection, the main shock and the underneath reflection shock form a "Λ" like structure;

2) In Fig. 5 and Fig. 6, it can be observed that, at the corner of the ramp, there is no obvious sign of shock waves, and the original shock wave retreats to a downstream position on the ramp. This result shows that the separation/reflection shock wave is eliminated near the corner.

3) In Fig. 6, it shows that the overall shock shape is rather irregular, especially at the foot of the shock. We can find that the shock is almost eliminated at the right foot side while it keeps in shape at the left side. The interaction between shock wave and vortex rings is fully 3D. The flow field lost its symmetry and it can be clearly illustrated by the shape of shock wave.

Multilayer structures and the bump like 3-D shape is one of the typical characteristics of the shock-vortex interaction.
4) When the vortex rings pass the shock wave, the shock wave will be distorted like a bump and the bump decreases its size when propagating downstream. The 3-D hump like surface can be observed through the window of the outer layer (see t_{1-3}), although the hump is not a complete one. This shape is mainly caused by the vortex ring-shock wave interaction.

Future work includes a deep numerical and mathematical study on shock-vortex ring interaction including the mechanism of deformation of shocks and vortex rings, pressure distributions and fluctuations, and the mechanism of reduction of the separation zone behind MVG.

References

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