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Compressible Vortex Loops in a Shock Tube with Helium Driver

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1 Introduction

It is the purpose of this study to evaluate the characteristics of the generation and propagation of compressible vortex rings in a shock tube where the physical properties of the gases, in particular density and specific heat, differ significantly. An experimental study has been conducted on the generation and propagation of compressible vortex loops using helium as a driver gas. The study aimed at evaluating the flow characteristics of a compressible vortex loop generated using a lighter then air gas into air at ambient conditions. The advantage of such system when compared to a constant gas system based on ambient air is to effectively increase the Mach number while keeping the pressure ratio constant. Three driver pressures were used (4, 8, and 12bar) generating a theoretical Mach number value of 1.53, 1.89, and 2.12 and an experimental mach number M_{se} of 1.43, 1.81, and 2.10 respectively. Qualitative and quantitative analysis were conducted. The generation of secondary vortex rings ahead of the main vortex ring were witnessed at all driver pressure. The structure of the trailing jet behind the vortex ring is shown to transition from a regular to a Mach reflection with increasing Mach disk size. The presence of the Mach disk results in the generation of vortical flow inside the main trailing jet with opposite circulation with respect to the outer jet boundary.

2 Results

Experimental results show that using a very light gas for the driver section increases the incidence Mach number for a given shock tube pressure ratio. A striking feature is the presence of the secondary counter rotating vortex rings at a Mach number lower then the established threshold of M_{se} ≈1.43 which may be attributed to the physical properties of helium (Fig.1).

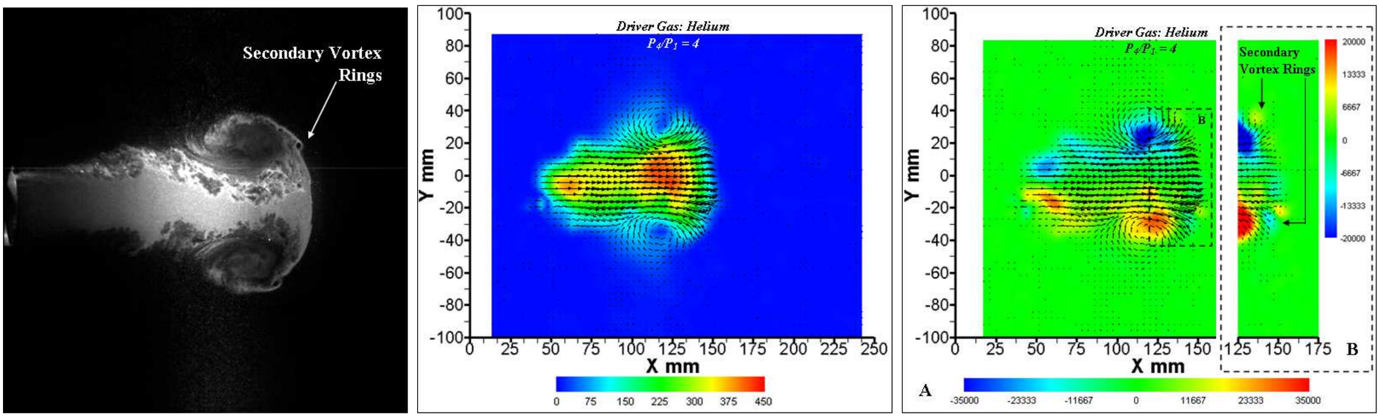

Figure 1: 30mm straight nozzle, $P_4/P_1 = 4$ at vortex ring structure (left), velocity magnitude (centre), and vorticity (right)

At the higher values of Mach number of 1.83 and 2.10 the flow structure of the vortex ring and trailing jet vary significantly. The pressure ratio along the jet boundary needs to remain constant forcing its shape to become curvilinear to compensate for the pressure variation. Similarly, the supersonic jet structure is affected with the converging compression wave growing in strength beyond the limit of a regular reflection and transitioning into a Mach reflection with a jet flow passing through the resulting Mach disk. Quantitative results at the higher experimental Mach numbers M_{se}=1.83 and 2.10 show that the presence of Mach disk has the effect of generating a jet with a lower velocity magnitude with respect to the surrounding flow. The velocity gradient between the two flow regions results in the formation of a shear layer with a circulation direction opposite to the one of the boundary of the main trailing jet as shown in the velocity magnitude and vorticity plot in Fig.2

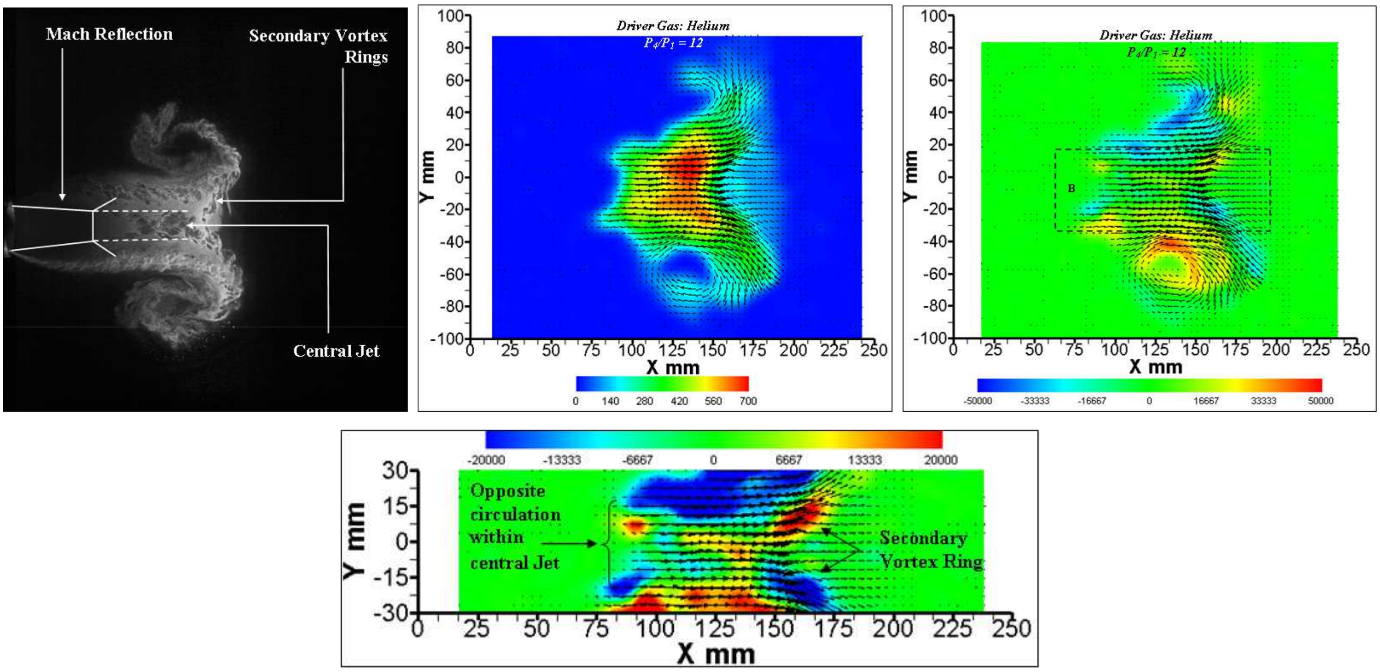

Figure 2: 30mm straight nozzle, $P_4/P_1 = 12$ at vortex ring structure (left), velocity magnitude (centre), vorticity (right), and shear layer with secondary vortex rings (bottom)