3D shock-bubble interaction

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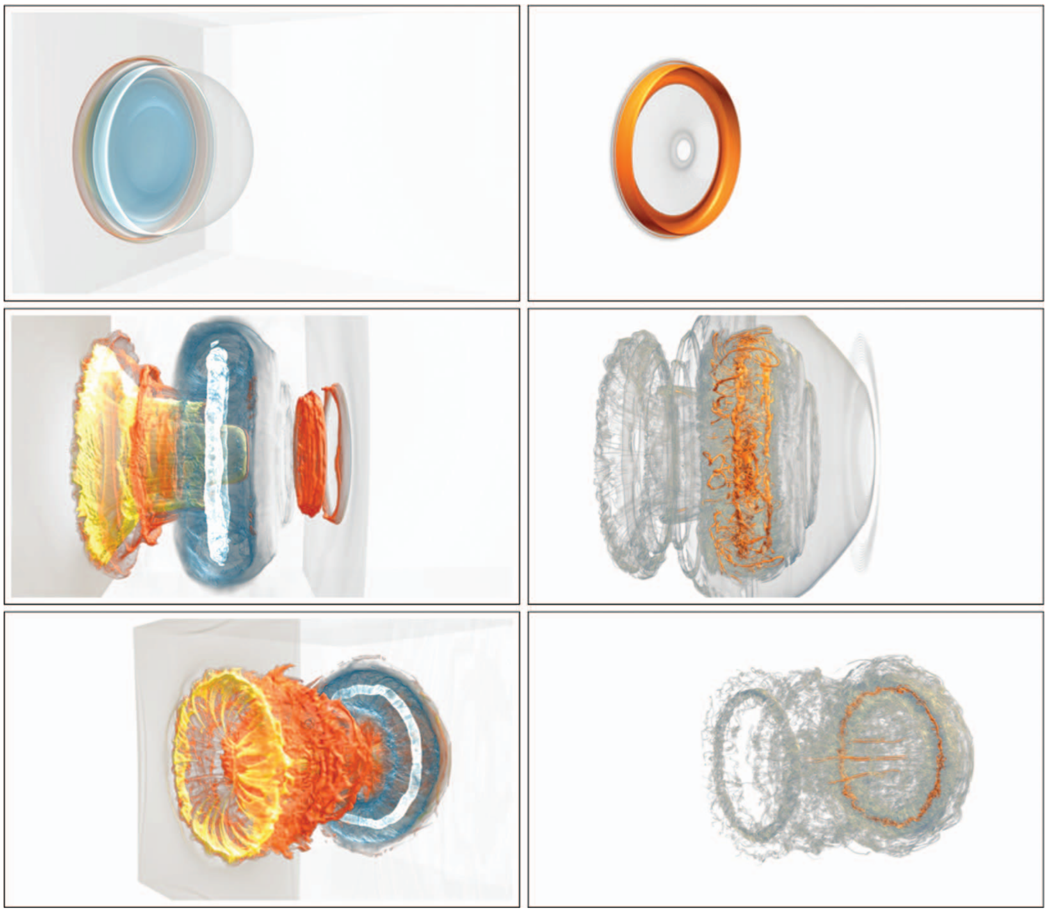

FIG. 1. Volume rendering of the density (left): orange/white denote high/low density. Volume rendering of the vorticity magnitude (right): orange/gray denote high/low vorticity magnitude. Chronologically from top to bottom (enhanced online) [URL: http://dx.doi.org/10.1063/1.4820017.1].

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We present detailed visualizations of the interactions of a normal shock wave at Mach 3, with a spherical helium bubble immersed in air,[1] with an interface Atwood number of −0.76 (Figure 1). The governing 3D Euler equations for two-phase compressible flows are solved using a finite volume solver with uniform resolution. We employ the 5th order WENO reconstruction of the primitive quantities, an HLL-type numerical flux, and the 3rd order TVD Runge-Kutta time stepping

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scheme. The software achieves 30% of the peak performance on a Cray XE6, using 4×10^9 cells. Extended simulations reveal that the shock passage compresses the bubble and generates baroclinic vorticity on the density interface. Initial distribution of the vorticity and compressions lead to the formation of an air jet, interface roll-ups, and the formation of a long lasting vortical core.

Shortly after the shock impact, the interface is compressed and vorticity deposition takes place on the frontal side ($\tilde{t} = 1.0$, top). Eventually the vortex sheet on the frontal side rolls up over the one on the distal side, forming a ring-like structure interacting with elongated azimuthal vortical structures ($\tilde{t} = 2.5$, middle). At a later time ($\tilde{t} = 4$, bottom), we observe an elongated structure with a sustained primary vortex ring and a plume-like region in the density field. Our analysis shows that at higher Mach numbers the initial dilatation of the generated vorticity is much stronger than the baroclinic source term. Furthermore, we show that the mid-plane circulation at late stages of the flow is proportional to the square root of the Mach number and the density ratio.

[1] D. Ranjan, J. Oakley, and R. Bonazza, "Shock-bubble interactions," Annu. Rev. Fluid Mech. **43**(1), 117–140 (2011).