Direct Numerical Simulation of Shock-Induced Drop Breakup with a Sharp-Interface-Method

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We present two- and three-dimensional numerical results of the shock-induced breakup of a liquid droplet in air. We apply a conservative interface interaction model for sharp-interface representation and a block-based multi-resolution scheme to adaptively refine our mesh. Numerical modeling effects, such as the flux reconstruction scheme and the use of a scale separation model, that treats non-resolved interface segments, are investigated.

Similarly as a previous study (Meng, 2016), we identify two dominant mechanisms of droplet breakup at certain Mach numbers - flattening of the droplet and sheet stripping - occurring simultaneously and influencing each other in our simulations. Three-dimensional simulations show the flattening mechanism and the mushroom-like deformation of the droplet. This flattening is caused by the non-uniform pressure distribution around the interface after the shock has passed. Two-dimensional simulations already exhibit the sheet stripping mechanism, which occurs during and after droplet flattening. As Meng, we observe one major sheet evolving from the drop equator, and a smaller sheet emerging from the planar downstream droplet segment. An additional smaller sheet is stripped from the upstream side of the droplet. This small sheet later merges with the main sheet. We believe that this small sheet is caused by pressure disturbances at the interface, which are caused by the wave dynamics in the surrounding flow field.

We also observe the occurrence of a recirculation zone in the droplet wake, whose generation can be explained from the three-dimensional simulations. The deflection of the flow at the droplet leads to a negative azimuthal vorticity stream emerging from the droplet equator. This stream entrains the area downstream of the droplet forming an upstream jet in the wake, thus the negative vorticity is advected upstream. The jet is deflected at the downstream side of the droplet, generating a positive azimuthal vorticity stream. This stream interacts with the negative vorticity stream at the droplet equator, forming there another recirculation zone. An additional recirculation zone is observed at the tip of the major sheet. We believe that it originates from the oscillations of the sheet: when the sheet moves towards the centerline, the previously aligned flow detaches and forms the recirculation zone.

REFERENCES

Figure 1. Numerical schlieren image (upper half) and normalized streamwise velocity component $u^*$ (lower half) at different instants.