Hypersonic Shock-Droplet Interactions

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How rapidly will a hypersonic shock wave vaporize a water droplet?

Atmospheric Vehicles travelling at speeds upwards of Mach 5+ and relatively low altitude. High (> 575e+) likelihood of encountering atmospheric hydrometeors (droplets), generally exist in range ~ 10 μm – 5mm

Impacts pose potential catastrophic damage to vehicle and mission failure:
• Surface Erosion and Ablation
• Mechanical Damage
• Heat Transfer
• Modified/ Unstable Aerodynamics

Methodology

Miranda
Used to solve the multi-component conservation equations for the transport of mass, momentum and energy
Discretization via tenth-order compact difference scheme
• Temporal integration with fourth-order Runge-Kutta method
• Eighth-order hyperviscosity, hyperviscosity, and hyperconduction with eight-order spectral-like deaaliasing for shock/interface capturing

Equations of State
Air:
• AESOP51 (Horak and Kodis)
Water:
• Two-Phase Liquid-Steam formulation (Nigmatulin & Bolotnova)

Shock Droplet Interactions

Instability Driven Breakup
• Aerodynamic deformation
• Kelvin-Helmholtz ; Shear Instability
• Rayleigh-Taylor ; Acceleration Instability

Multiphase Physics
• Heating (thermal transport)
• Evaporation
• Vapor species advection
• Supercritical regimes
• Cavitation
• Internal waves interaction
• External aerodynamics/dynamic pressure

Simulations

0.00 μs
0.50 μs
0.75 μs
1.00 μs
1.25 μs
1.50 μs

Conclusions / Future Work

• Disagreement in droplet breakup/survival time with empirical predictions (Reinecke)
• Models fail to capture coupled time-dependent breakup, evaporation behaviors

Future Work:
• Parameter study; varied droplet diameters, varied Mach number, initial RT (atmospheric/flight conditions)
• Variable acceleration/ shock coupled with expansion wave (compression wave)
• Development of reduced order models

Acknowledgements

I would like to acknowledge Andrew Cook, Bradley Perfect, and Hassan Beydoun as well as the Miranda and Flight Sciences teams and DSTI program management.

References

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

LLNL-POST-852111