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Ph.D. DISSERTATION DEFENSE

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Title: High Mach Number Aerobreakup

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ABSTRACT

One fundamental consideration in high-speed vehicle design is that high-velocity drop impacts can degrade materials, reducing transparency and other desirable properties. Drop sphericity and size can change the degree of impact damage. The flow structure about high-speed vehicles can disrupt drops, altering impact effects. Therefore, the study of high-speed drop impact must begin with characterization of drop evolution between initial shock processing and impact.

Aerobreakup in the stagnation region of high-Mach number flow over a bluff body is studied experimentally. Imaging techniques including digital in-line holography (DIH), planar laser-induced fluorescence (PLIF), and shadowgraphy were evaluated to determine suitability for studying aerobreakup. Two experiments were designed and performed to image drops during collision with high-speed projectiles using shadowgraphy.

First, drops were introduced into a ballistic range and impacted by high-speed projectiles. Shadowgraphs revealed that the low-pressure (≈ 20-30 kPa) environment and hemispherical projectile shape provided insufficient interaction time to characterize aerobreakup, though impact jetting was measured and practical elements of high-speed imaging were demonstrated. Second, drops were levitated at sea level along the path of 100 mm x 150 mm flat-faced projectiles launched electromagnetically at the Naval Surface Warfare Center Dahlgren Division. This enabled the study of aerobreakup at high Mach (3.03-5.12), post-shock Mach (1.5-1.9), and Weber (5e4-4e5) numbers, with accompanying computations performed by Christoph Brehm and Manuel Viqueira-Moreira at the University of Maryland. It was found that flow around the drop can be adequately captured by treating the gas as calorically perfect with a specific heat ratio of 1.3 (to account for thermochemical effects), and that drop behavior is not dominated by viscosity or surface tension. To assess surface stability, flow along the drop surface was computed using Newton's method. It was found that drop surface disturbance growth is dominated by acceleration at the stagnation point while shear dominates near the drop equator. Linear-stability analysis was insufficient for modeling aerobreakup because it predicted instability wavelengths and aerobreakup times much smaller than those observed experimentally. A nonlinear instability model with constant-rate growth was developed that treats disturbance growth as analogous to bubbles rising through liquid; agreement of this model with computations is good.