Aerodynamic Dissemination

Daniel Joseph, University of Minnesota

Army Issue

Predict the dissemination of liquid agents after interception of a theater missile.

Basic Science Issue

Determine how a thick liquid breaks up into a cloud of vapor and mist in a high mach number (mach 3 to 8) air stream at high altitudes.

Water in High Speed Air Flow

- The flow separates; low pressure develops on lee side.
- Micron-sized drops are stripped off the sides of the liquid mass.
- A cloud of vapor and mist (micron-sized drops) is formed.
- The properties of the cloud do not depend strongly on the size of the original liquid mass provided it is much larger than the large drops in the cloud.

Thickened Agent in High Speed Air

- Agents are usually viscoelastic.
- Threads strip off the sides of the liquid mass; droplets do not form.
- A cloud of vapor and mist consisting of small micron-sized drops is formed.

Missing Mass

- In tests conducted at Edgewood, Dugway and Arnold over the past 30 years, around 60% of the original mass could not be accounted for on collection surfaces for droplets.

- The most recent experiments have indicated that the missing mass is present in the form of vapor that condenses to form mist.

- Analytical and computational effort is focussed on mechanisms that can produce the heat and lee-side low pressure necessary for flash vaporization (cavitation) within 500 μsec (insufficient time for evaporation alone to produce vapor).

- Aerodynamic heating from hot gas behind a shock is not a sufficient mechanism because the thermal diffusivity of the liquid is small.

Approach

- Use of all available data from Army tests and scientific literature
- Physical modeling
- Mathematical analysis
- Computational simulation
- Experiments: high mach number shock tube

Specific Issues of Army Interest

- Determine volume fraction of vapor and drop size distribution of mist
- Determine effect of thickening agents

Our Previous Work

- Identified error in Keith-Banks correlation; this is no longer used
- Introduced the Weber number, Ohnesorge number, Rheology based on wave speeds
- Flash vaporization mechanism for vapor production
- Carried out the first energy balances. The huge kinetic energy of the liquid mass goes into formation of new surface on small drops, phase change to vapor and heat

Flash Vaporization

- Occurs in superheated liquids (low pressure, high temperature)
- In a static fluid, cavitation occurs when the mean normal stress > the cavitation threshold. In a fast-deforming liquid drop or thread, the principal normal stresses are not all equal. Cavitation occurs when any one of these principal normal stresses > the cavitation threshold

Mechanisms

- Acceleration of the drop
- Low lee side pressure
- Friction due to rapid deformation, hot gas behind the shock
- Large extensional stress. I think that breaking threads always give rise to vapor, no matter what

Payoff

- Accurate understanding of what happens to be the payload after exposure to high speed air
- Input for dispersion models after impact
- Understanding of physics of control breakup
- Shock tube facility with skills, people and know-how to do army tests on high speed shock dynamics for different application at LOW COST
- Collaborations with ERDEC, SAIC and other ARMY organizations