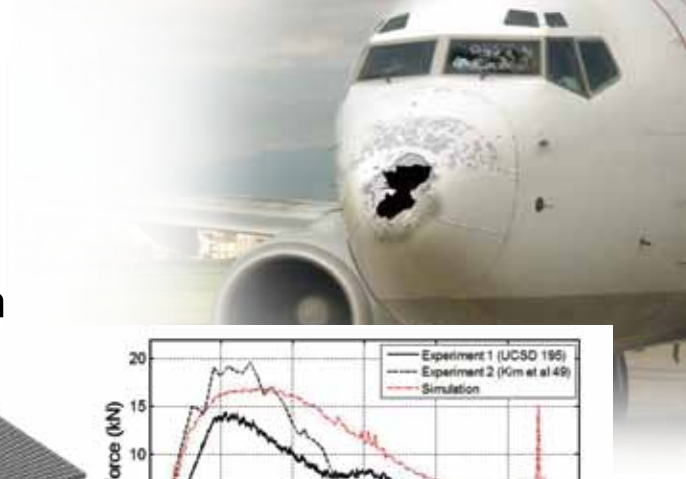


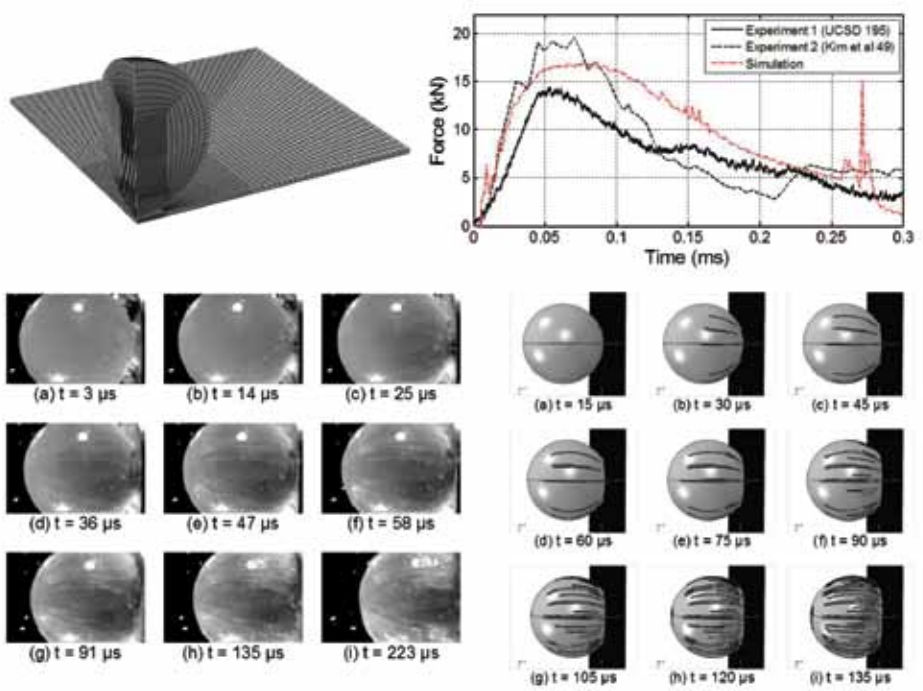
Strain Rate Sensitive Ice Material Model for Hail Ice Impact Simulation

Ice impacts and the ensuing dynamic loading are significant issues in many fields, such as ship building, arctic researchers, aviation, and interplanetary space missions. Hail impacts have always been of interest to aviation, particularly in engine structures. Within the last decade this threat has become of greater importance in aviation due to the significant use of composite materials, such as carbon fiber reinforced plastics, in exposed primary structural components. Because new aircraft are using complex composite laminates, numerical simulations can provide information about internal stress states, damage initiation, and growth, which can be difficult to directly measure via experiments.

In order to produce accurate predictions of a composite structure impacted by hail, the ice projectile properties must first be accurately modeled. In this case, the projectile properties modeled are of hail ice spheres. An improved strain rate dependent model was developed for use in Abaqus by University of California at San Diego graduate student Jeff Tippmann, under the guidance of Professor Hyonny Kim of the Structural Engineering Department and with assistance from graduate student Jennifer Rhymer, and partially funded by the FAA.

The ice material model included elastic properties, strain rate dependent yield strength, and a tensile-pressure failure criterion. The strain rate dependent yield strength was the main improvement from past models developed by previous researchers in academia. The newly developed model uses strength data at impact strain rates measured by previous researchers. All previously developed models required the tuning of various material parameters for different impact speeds and projectile sizes. With the added strain rate dependent yield strength in Abaqus, the new material model does not require any adjustments.

During development, the simulation results were compared to experimental measurements of dynamic forces generated during an ice sphere impact onto a force measurement bar. Several parametric studies were performed to study the material parameters, as well as the mesh density. Because there was a considerable scatter in the experimentally measured ice strength data, the final material model incorporates the ability to use a lower bound, average, or upper bound strength curves.



(Top-left) Quarter-symmetric model of ice sphere and rigid target (Top-right) Force history comparison of simulation results (red) with experimental data (black) (Bottom-left) High speed video frames of 50.8 mm diameter ice sphere impact at 60.6 m/s (Bottom-right) Cylindrically patterned view of quarter-symmetric model and deformation with elements failed by tensile failure pressure criterion removed from viewport

The Abaqus simulation results show a strong agreement with the experimental results, with the lower bound and upper strength curves bounding the peak forces observed. Additionally, using high-speed video images of the ice sphere impact, the cracking was observed to propagate along the projectile in a direction away from the initial impact side and continue growing as the impact force increases (up to 0.05 ms). Once the peak force occurred, transverse cracks also formed and the ice sphere began to fragment into many pieces. Thus, the forces created by high-velocity ice impact can be defined by two major phases: (i) elastic-dominated structural response during initial time following first contact in which cracks develop and the impact force is increasing, and (ii) fragmentation and cracking, which imparts mainly a momentum-based loading that corresponds with the decreasing force trend following the peak force.

The cracking can also be observed visually in the simulation by removing the failed elements from view. As with the visual experimental observations of the ice sphere impact, the cracks propogate from the impact side of the projectile and reach their maximum length when the peak impact force is reached. However, the simulation does not predict the fragmentation of the projectile after the peak force. Therefore it is important to distinguish that the model is particularly suited for predicting early time-scale events loading up to peak force and initial localized failures in the structures impacted by high-velocity hail ice, and not the spray pattern and debris flow of ice well after it strikes a surface.

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For More Information

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