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IMPROVED EQUATIONS OF STATE AND STRENGTH MODELS FOR ASTEROID IMPACT AND DEFLECTION

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ABSTRACT

On impact with the surface of a planet, asteroids and comet nuclei may induce shock pressures up to ~5 TPa. Even higher pressures may be generated if a nuclear explosion is used to deflect a body. The extent and magnitude of shock and blast effects from an impact, and the effectiveness of deflection by impact or explosion, depend on the pressure-volume relation for material expanding from the initial, shocked state. Shock states in some relevant compositions have been measured up to ~2 TPa, but far fewer measurements of the release isentropes have been made, and almost no measurements of any type exist at higher pressures.

We are developing experimental platforms to enable shock and release measurements, using planar and converging shocks at the National Ignition Facility and Omega laser, and the Z pulsed power machine. With a converging shock, a single experiment can explore a range of shock pressures, and a higher peak pressure can be induced for a given size of drive laser, at the expense of potentially lower accuracy in comparison with a planar shock.

In parallel, we are using quantum molecular dynamics (QMD) to predict thermodynamic states in relevant materials on compression and heating. At low densities, where QMD becomes less tractable, we use equilibrium chemistry based on analytic potential functions. This combination of experimental and theoretical data allows us to construct scalar equations of state that are wide-ranging and robust. A complete calibration for a single composition is, however, expensive and time-consuming; a wide range of compositions is needed to address all likely asteroid and comet structures and impact scenarios. We are using mixture models inline in hydrocode simulations or during the construction of an equation of state, so that a smaller number of key compounds can be combined to address a wider range of geologic and ice compositions.

Compressive and tensile strength are important aspects of the response of materials to dynamic loading, and may depend sensitively on the microstructure and initial temperature. Strength properties are much more difficult to predict theoretically, and it is important to understand the size-strength scaling of heterogeneous mixtures. We have developed sample holders to control the initial temperature in laser experiments from ~80 K representative of asteroid and comet interiors to ~1000 K. Strength experiments are made at much lower pressures than are needed for the shock states described above; smaller laser facilities in the ~100 J class are suitable. We have also inferred strength from microindenter measurements; samples may also be heated or cooled. Microindentation shows spatial variations in strength from variations in composition and microstructure, and probes the response at low strain rates typical of atmospheric entry.

The mechanical properties of a limited number of meteorites will be measured on macroscopic samples, using gun facilities at Arizona State University and NASA Ames. Measurements will include tensile, torsion, and shear strengths, longitudinal wave speed, and impact disruption. Detailed maps of surface textures, and fractal analysis of meteorite fracture surfaces will be obtained for a representative set of meteorites.

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