VERIFICATION AND VALIDATION OF THE RAGE HYDROCODE IN PREPARATION FOR INVESTIGATION OF IMPACTS INTO A VOLATILE-RICH TARGET.
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Introduction: Before a hydrocode is used to investigate a question of scientific interest, it should be tested against analogous laboratory experiments and problems with analytical solutions. The Radiation Adaptive Grid Eulerian (RAGE) hydrocode[1], developed by Los Alamos National Laboratory (LANL) and Science Applications International Corporation (SAIC)[2,3] has been subjected to many tests during its development.[4,5] We extend and review this work, emphasizing tests relevant to impact cratering into volatile-rich targets.

RAGE: is an Eulerian radiation-hydrodynamics code that runs in a variety of geometries in up to three dimensions, with a variety of equations of state. It was developed for general application, so it does not include *ad hoc* tuning of algorithms or parameters, but relies solely on physical first-principles. RAGE uses a higher order piecewise linear Godunov numerical method to solve the hydrodynamics equations.[6,7] An exceptional advantage to this code is its use of a time- and space-continuous adaptive mesh refinement (AMR), by which it is able to follow shocks and other discontinuities at high resolution while treating smooth regions coarsely, increasing computational efficiency. The radiation component of the code is an optional grey diffusion model with nonequilibrium radiation and material temperatures.[8] Opacities are generated as part of the SESAME equation of state tables, or optionally from an analytic model.

Verification. This process ensures that the model is coded and solved correctly. RAGE is subject to an extensive set of tests in which output of each version of the code, on every computer system on which it is run, is compared to analytical solutions and results of previous versions of the code in order to demonstrate invariance under different running and boundary conditions. Test problems include the Sod shock tube[9] demonstrated in this study, the Noh problem, which checks for errors from shock 'smearing' by finite resolution[10], the Sedov blast wave, which scales self-similarly in time[11], Marshak waves, which tests radiation diffusion [12], and many other problems [4].

Validation. This process ensures that the model is appropriate to the problem at hand, and of sufficient accuracy. To validate the RAGE code, many simulations are used to replicate physical experiments. These include examinations of fluid instability in a shock-accelerated thin gas layer[13], Richtmyer-Meshkov instability growth[14], supersonic fluid flow and shock-induced jetting[15], and shock transmission through boundaries [16]. We extend this effort to shocks in basalt and ice.

SESAME: is a temperature-based tabular equation of state maintained by the Mechanics of Materials and Equations of State group LANL. The table for each material has a unique and thermodynamically consistent fit of semi-empirical theoretical models appropriate to different temperature or pressure regions to experimental data[17,18].

Method: We conduct four simulations of particular relevance to impact modeling. The first is a reproduction of the one-dimensional shock tube verification problem published by Sod[9]. Initially the 1-D planar tube is divided into two sections. In the left section, a gas is in equilibrium at a higher density and pressure (ρ_1=1.0, p_1=1.0, u_1=0.0). In the right section, the gas is in equilibrium at a lower density and pressure (ρ_2=0.125, p_2=0.1, u_2=0.0). At t=0 the high-pressure/density gas expands into the low-pressure/density region, generating a shock wave. The hydrocode results are compared to the analytical solution to demonstrate the accuracy of the finite differencing scheme. The second and third tests reproduce shocks in basalt[19] and water ice[20].

Results: The Sod shock tube performed well. Further tests are ongoing. Detailed results will be presented at the workshop.

Sod Ideal Gas Shock Tube. This model corresponds to the shock tube described above[9], and compared to the analytical solution. Results were graphed for density, velocity, pressure, and specific internal energy at t=0.12 seconds (fig. 1-4), just before the shock wave hit the end of the tube.

Ice Shock Tube. In this experiment[20], aluminum and polycarbonate projectiles were fired into water ice slabs of thicknesses ranging from 3-60 mm. They measured pressure, attenuation, and propagation velocity. In RAGE, we will use a one-dimensional column where an aluminum[21] or polycarbonate[22] projectile strikes an ice (SAIC proprietary water equation of state) target at t=0, at velocities ranging from 300-600 m/s, as in Kato[20]. Pressures and velocities will be recorded for comparison with the original data.

Basalt Shock Tube. In this experiment[19], a copper projectile was fired at a column of basalt plates interleaved with pressure sensors, generating peak shock pressures from 7-9 GPa. They measured the pressure over time through the column. In RAGE, we will use a one-dimensional column where a copper[23] projectile will strike a basalt[24] target at t=0, at velocities between .68-2.7 km/s. Shock pressure and propagation will be recorded for comparison with the original data.

Future Work: When we are confident that verification and validation criteria have been met, we will use the RAGE hydrocode to examine in two dimensions the effects of sub-surface volatiles, such as water ice, on the propagation of impact-generated shock waves through the Martian surface.

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Acknowledgments: UCSC/LANL Institute of Geophysics and Planetary Physics, NASA PG&G Small Bodies and Planetary Collisions.

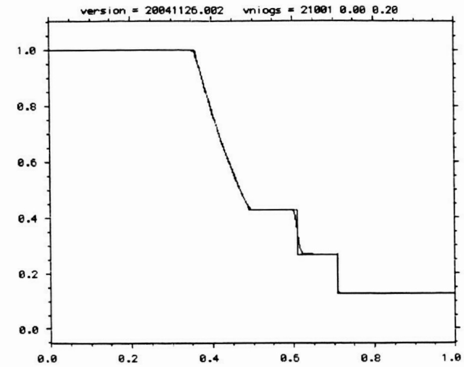

Figure 1. Sod ideal gas shock tube density vs. distance, analytical and RAGE solutions at t=0.12 s.

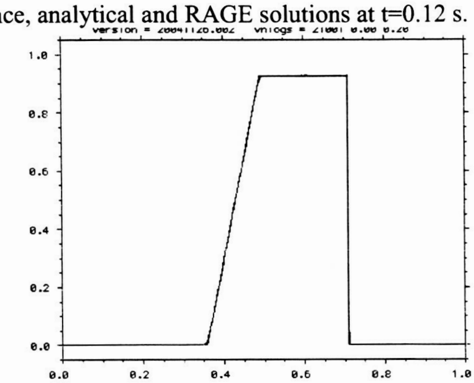

Figure 2. Velocity vs. distance, t=0.12 seconds.

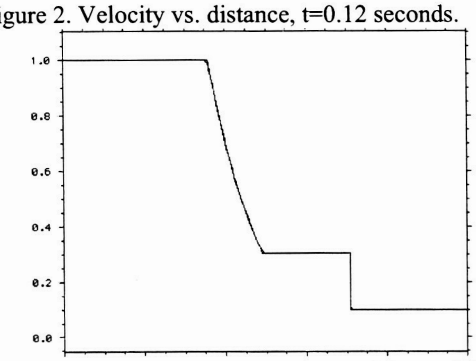

Figure 3. Pressure vs. distance, t=0.12 seconds.

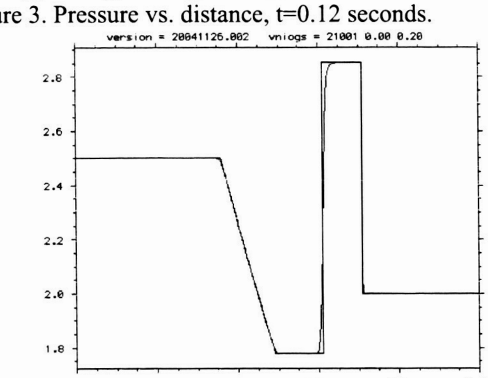

Figure 4. Specific internal energy vs. distance, t=0.15s.