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SCRAM Progress

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Summary: The main thrust in SCRAM has been to generate a 3D stand-alone version that can be combined with 3D finite-element or finite-difference codes to calculate impact damage, ignition, and burn of explosives. The algorithm has been combined with CFDLIB (Computational Fluid Dynamics LIBrary) and its functionality verified by running a spherical explosion problem. Point symmetry of the spherical flow provides an important test of the method. One of the goals of the 3D version is to account for the radial cracking observed in damaged explosives. Since the radial cracks are erratic, this requires, in addition, introducing a random crack distribution to represent regions of reduced strength. The main challenge is to develop a method to make the transition from microcracking to macroscopic fracture. An approach has been developed, but will require considerable care to carry through to a successful implementation.

Stand-Alone SCRAM: SCRAM (Statistical CRAck Mechanics) is an algorithm that represents the behavior of materials as cracks open, shear, grow and coalesce and, in addition, accounts for plasticity and high-pressure behavior. Plastic behavior is accounted for with kinematic hardening, and high-pressure behavior with a Mie-Gruneisen equation of state. Since yield and fracture behavior occur under different criteria, the model accounts for the brittle-ductile transition. It should be emphasized that these kinds of behavior are quite different, since plasticity is stable and lies within the scope of thermodynamics, while microcracking is essentially unstable, and requires a different approach. SCRAM was developed to address this issue, and accounts for mechanically unstable behavior. The stand-alone version is useful to test out various parts of the code without the need to couple it to the equations of motion. This is done by inputting the rate of deformation and computing the resulting stress. Stress-strain curves are plotted to verify the behavior under complex strain histories. The underlying assumption that makes this algorithm feasible is the Principal of Superposition of Strain Rates, a generalization of the Prandtl-Reuss ansatz for elastic-plastic flow.

Ignition: Explosives and propellants can ignite when impacted at very low speeds, but the mechanism behind this process has never been fully understood. In SCRAM we have hypothesized that hot spots are formed where closed cracks shear (Mode 2 and Mode 3 fracture), and the interfacial friction causes local heating. Heat conduction combined with reactive heating results in ignition after a finite time, and in SCRAM we have implemented this process and compared the results with published results (in which heating occurs by a radiative mechanism). The heating causes melting before ignition in many cases, and this tends to reduce the heating. Recent results by Sewell (T-14) and others have resulted in a temperature-dependent viscosity that is considerably higher than we had previously assumed. This result brings our multiple-shock ignition calculations into better agreement with the experimental results of Mulford et al. (DX). For many years we attempted only the ignition of explosives and propellants, but more recently we have been concerned with the burn that follows ignition.

Explosive Burn: In ignition, it is sufficient to treat the thermal and reactive behavior of the condensed phase, but in burn there is a gas phase which requires different considerations and new physics. We have developed a treatment for burning cracks that is suitable for post-ignition behavior of explosives, but the treatment has brought out some new issues that give pause. The problem is that a burning crack has a gas in the interior that causes the crack to grow if the pressure is high enough, but the crack volume grows so rapidly that the pressure drops to a very low value, causing the hot spot to quench. Thus, an isolated hot spot does not lead to violent reactions. However, crack interactions can cause violent reactions as the pressure from

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one enhances burning in the others. These results were presented at a meeting at Cal Tech and a paper describing detailed calculations has been accepted for publication.

Crack growth and burning could, conceptually, be described by a finite-element code, but only with great difficulty, because the zoning problems at the crack tip, a singular region, are quite intractable as the crack grows. We consider this method impractical as a part of our subgrid crack modelling and have taken a different approach, in which the crack dynamics is governed by Lagrange's equations. Crack opening and radius are taken as the generalized coordinates, leading to two ordinary differential equations. The radius increases or remains constant depending on whether or not the pressure exceeds the critical value. Crack speed is close to the theoretical value. These equations form the basis for the calculations described in the preceding paragraph. This approach to crack dynamics has been verified by modelling Mulford's multiple-shock ignition experiment (reported at the Detonation Symposium).

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