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TITLE

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MESA: A 3-D Eulerian Hydrocode For Penetration Mechanics Studies

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ABSTRACT

We describe an explicit, finite-difference hydrocode, called MESA, and compare calculations to metal and ceramic plate impacts with spall and to Taylor cylinder tests. The MESA code was developed with support from DARPA, the Army and the Marine Corps for use in armor/anti-armor problems primarily, but the code has been used for a number of other applications. MESA includes 2-D and 3-D Eulerian hydrodynamics, a number of material strength and fracture models and a programmed burn high explosives model.

1. The MESA Code

MESA is a three-dimensional, cartesian, explicit, finite-difference Eulerian code with hydrodynamics, high explosives, and material strength models. The two-dimensional algorithms have been described by Youngs¹. The hydrodynamics is divided into two phases. The first phase is a pure Lagrangian calculation, and the second phase is a remapping back to the original Eulerian mesh. Operator splitting is used. That is, the calculations are done in the x, y, and z-directions during one time cycle, and then in the z, y, and x-directions during the next cycle. an Leer² limiting is used in the advection phase in order to maintain steep gradients without introducing nonphysical oscillations.

A unique feature of MESA is the interface reconstruction algorithm, which was developed by David Youngs³. This model allows fewer cells to be used for the same accuracy than in older codes since mixed-cell material interfaces are calculated accurately. The interface reconstruction method assures that materials are advected in the correct order.

Yield models include the Steinberg-Cochran-Guinan⁴ model with work hardening and thermal softening, and the Steinberg-Lund⁵ and Johnson-Cook⁶ models with strain-rate hardening as well. The mechanical Threshold Stress (MTS) model has also been implemented into MESA⁷. The von Mises yield criteria is used. Fracture models include the Johnson (Jim) ductile spall model⁸ and the Johnson (Gordon)-Cook fracture model⁹. For brittle materials we have implemented the Johnson-Holmquist¹⁰ model.

We use the standard JWL¹¹ equation of state (EOS) for the high explosive (HE) and currently treat detonations with a programmed burn.

In addition to the JWL EOS for the HE detonation products, a number of analytical EOS equations are available for other materials. The Los Alamos tabular equations-of-state, SESAME¹², are also available in MESA.

2. Tantalum Plate Impact Problem

For this calculation, we compared calculations of tantalum-on-tantalum plate impacts with experiments¹³ at an impact velocity of 0.039 cm/ μ s. This is a one-dimensional problem, so we only used a few cells in the y- and z-directions. The problem was zoned on a uniform rectangular mesh with cell sizes of 0.01 cm on a side. The impactor was 0.305 cm long, and the target was 0.96 cm long.

Fig. 1 shows the comparison with experiment of MESA calculations using the elastic-perfectly-plastic, the Steinberg-Guinan, the Steinberg-Lund, and Johnson-Cook models. For these calculations, the Johnson spall model was used to model the ductile fracture. All models show the turnaround in the curve, although none match the data exactly. However, it was necessary to make an educated guess for the constants in the Johnson spall model for tantalum since it has not yet been characterized.

Fig.1 Comparison of the free surface velocity measured as a function of time for a tantalum-on-tantalum impact experiment at a velocity of 0.039 cm/ μ s with the results of MESA calculations using the elastic-perfectly-plastic, Steinberg-Guinan, Steinberg-Lund, and Johnson-Cook yield condition models.

3. Taylor Anvil Test Problem

For the Taylor cylinder problem, we considered a copper cylinder that was 1.0 inch long and 0.33 inches in diameter (2.54 cm by 0.762 cm), traveling initially at a velocity of 190 m/s. The problem was zoned on a uniform rectangular mesh (54 x 16 x 16 cells) with a cell size of 0.05 cm on a side. Due to its axisymmetric nature, we only considered one-quarter of the problem to save computer memory and time. The problem was run to 70 μ s, at which time the deformation of the cylinder appeared to be complete. (The shape of the cylinder did not change from about 60 μ s on.)

The strength model in a hydrocode is crucial if one hopes to match the experiment for this problem. If only fluid-flow (hydrodynamics) is considered in the calculation, the cylinder will continue to spread out as it hits the wall, and will never stop. We tried four strength models: elastic-perfectly plastic, Steinberg-Guinan, Johnson-Cook, and the MTS models.

In the experiment, the deformed shape of the cylinder after impact was recorded as radius y vs the length. We compare the outside surface of the cylinder in the calculation with the outlines of the deformed cylinder from the experiment. Fig. 3 shows the computed outline of the cylinder using three different yield surface models. (The plot is of the outline of only half of the cylinder in one plane.) Since the original length of the cylinder was 2.54 cm, one can see that a significant amount of deformation has occurred.

Fig. 3. Comparison of the deformation of a copper Taylor cylinder (after an impact at 190 m/s) as observed in the experiment with calculations using three different yield strength models: elastic-perfectly-plastic, Steinberg-Guinan, and Johnson-Cook.

Note in this comparison that the Steinberg-Guinan model best reproduces the curvature of the main body of the cylinder, while the Johnson-Cook model best reproduces the shape of the toe. All three models underpredict the final compression of the cylinder. The elastic-perfectly-plastic model calculation shows an unphysically large amount of spreading of the cylinder wall. The constant yield strength for this model was chosen to be the experimental value for copper at room temperature and one-atmosphere pressure; by choosing an intermediate value for the yield strength, one might be able to match the data better. Using a cell size of 0.025 or 0.10 cm rather than the 0.05 cm of the above calculation has only a small effect on the results.

Fig. 3 Johnson-Cook and Mechanical Threshold Stress Model Comparisons With Data

Fig. 3 compares MESA calculations using the Johnson-Cook(J-C) model and the MTS model with an experiment at an impact velocity of 146 m/s. Note the excellent agreement that the MTS model calculation gives with data. Johnson-Cook results from the EPIC Lagrangian code (not shown) overlay the MESA results ¹⁴indicating that the Johnson-Cook model was implemented in MESA correctly and that the Eulerian advection did not effect the results.

4. Ceramic Plate Impact

Plate impact results for a MESA 2-D calculation using the Johnson-Holmquist model are compared to SiC data obtained by Kipp and Grady¹⁵ in Fig.. 4 The impact was at a velocity of 2.1 m/s. For this ceramic, which behaves very much like a metal, the

agreement is excellent. Further calculations on other materials are in progress. As with the Taylor cylinder results, MESA and EPIC results overlay each other.

Fig.4. Free Surface Velocity For An SiC Plate Impact

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