Computational studies of the skid test: Evaluation of the non-shock ignition of LX-10 using HERMES

B W White[1]**, H K Springer**[2] **and J E Reaugh**[2]

[1]Computational Engineering Division, Lawrence Livermore National Laboratory, 7000 East Ave., Livermore, CA 94550
[2]Chemical Science Division, Lawrence Livermore National Laboratory, 7000 East Ave., Livermore, CA 94550

E-mail: `white234@llnl.gov`

Abstract. We perform computational studies to evaluate the non-shock ignition response of LX-10 ($95wt.\%$ HMX, $5wt.\%$ Viton A) during a skid impact test. We employ the HERMES (High Explosive Response to MEchanical Stimuli) model for LX-10 for Skid test calculations investigating the influence of drop height and angle on the pressure, strain-rate, strain, and ignition states. While grit is typically present in skid tests, it was not considered in these continuum-scale calculations. We found that the incident angle has a much more significant influence on pressure, strain-rate, strain, and ignition states than drop height. The peak HERMES ignition parameter value, *Ign*, is nearly one order of magnitude higher for an incident angle of 45° than for 14°. Peak *Ign* values occur at the contact patch where shear deformation is highest and is a result of the shear-dependence in the ignition criteria. While peak *Ign* values for Steven Tests were approximately 60, the skid test had a much smaller value < 2 for the scenarios considered in this study. The discrepancy in ignition values suggest that grit-explosive interactions play a significant role in skid test response. Since the peak ignition values are much less for the 14° impact angles, the role of the grit may be more important at lower incident angles. Future work should include meso-scale calculations to resolve the localized grit interactions that underpins these shear ignition mechanisms.

1. Introduction

In this study we examine the skid test which is used to measure the relative non-shock ignition sensitivity of explosive billets to oblique impacts. The skid test uses a large hemispherical billet of high explosive (HE) that is suspended by support wires from a pole to form a pendulum (see figure 1). Each test, the apparatus is modified so that the billet strikes an impact plate at different angles from predetermined drop heights. The impact plate consists of a steel slab that has a layer of sand epoxied to its surface. The skid test has impact angles that are either 14° or 45° and drop heights that range from <1 to 20 feet. For each impact angle the highest minimum drop height for which six consecutive tests show no reaction is the critical height and used for ranking the relative sensitivity of HE. Any drop height above this level was found experimentally to ignite with varying levels of reactivity which is assessed and assigned a value between 0 for no reaction, and 6 for full detonation. Reaction levels of 1 or 2 are for the presence of mild-scorch marks and/or smoke, 3 or 4 for partial and moderate burns, and 5 for a violent reaction [1].

LX-10 ($95wt.\%$ HMX, $5wt.\%$ Viton A) was fairly sensitive, having critical heights ≥ 0.88 ft for an impact angle of 14° and ≥ 2.5 ft for an impact angle of 45° (see table 1). LX-10 also
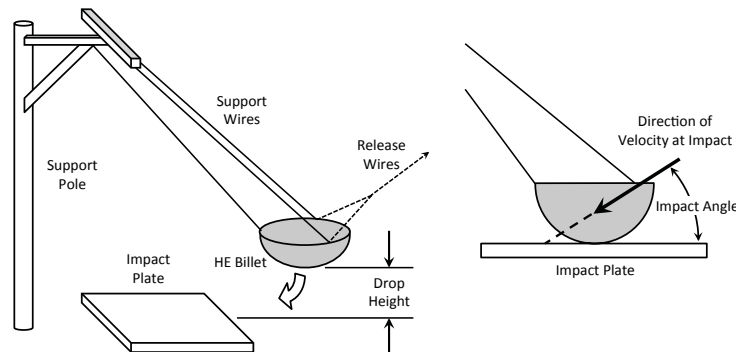
Figure 1. Simplified schematic of the skid test apparatus (not to scale). Modifying the length of the support wires and the location of the impact block may be used to control the drop height and impact angle.

either detonated completely (reaction level = 6) or not at all (reaction level = 0). Because of the sharp transition observed in LX-10, it is an ideal HE to examine the role slight differences in drop height or impact angle have on the internal states of the HE. The experimental data has statistical variability which may be indicative of variability in either the test conditions and/or the heterogeneous nature of the HE microstructure.

The HERMES model [2–4] consists of a pressure-dependent and strain-rate dependent strength, and a non-shock ignition criteria. It is ideal for evaluating the combined shear-pressure ignition response under skid test conditions. The dimensionless HERMES ignition parameter value, Ign, is based on a weighted integral of plastic strain, pressure, and shear effects (see equation (1)). Once the ignition criteria has been reached, the reaction front will numerically propagate from that region of the explosive and activate the post-ignition components of the model.

$$Ign = \int_0^t \left(\frac{P - s_2/2}{\sigma_n}\right)^{pn} \left(2 - \frac{3|s_2|}{Y}\right)^{ps} \dot{\varepsilon}_p dt \tag{1}$$

In equation (1), s_2 is the intermediate principal stress, Y the yield stress, pn and ps are power terms used in the shear and normal components respectively, σ_n is the normal stress, and $\dot{\varepsilon}_p$ the effective plastic strain rate.

Table 1. Experimental skid test results for LX-10 [1].

Impact Angle (°, degrees)	Drop Height (ft)	Reaction Level (–)
14	0.88	0,0,0,0,0,0,0
	1.25	0,6,6,0,6,6
	1.75	0,6
45	2.5	0,0,0
	3.5	0,0,0,0,6,6,0,0
	5.0	6
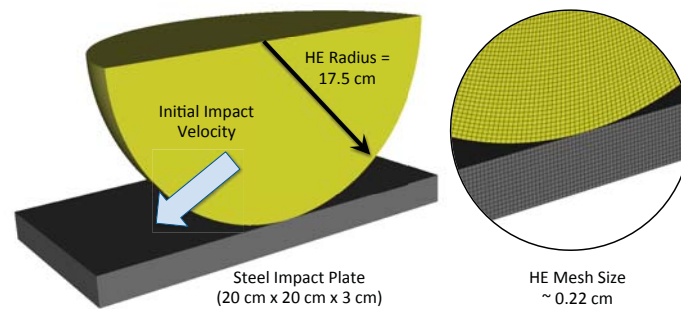
Figure 2. Geometry used in ALE3D skid test simulations. The magnitude of the initial velocity is determined from the drop height. The mesh near the point of impact is also shown in the image on the right and has a size approximately 0.22 cm.

2. Model Description

One-half symmetry, 3D simulations of the skid test were conducted using ALE3D to examine the effects of drop height and impact angle on LX-10. The drop heights considered, were 1.25 and 1.75 feet for an impact angle of 14° and 3.5 and 5.0 feet for an impact angle of 45°. The drop heights were used to determine the magnitude of the impact velocity. The impact plate was modeled as steel with a coefficient of friction of 0.4 between the steel and LX-10. HERMES was used to model the billet of LX-10. A Lagrangian treatment of the mesh was used which had a size of approximately 0.22 cm. The simulation domain is shown in figure 2 along with a closeup view of the mesh near the region of most interest. The sand layer that is commonly epoxied onto the impact plate was not modeled in these simulations.

3. Skid Test Simulation Results

3.1. Pressure within a Billet of LX-10

The maximum pressure, strain-rate, strain, and ignition value were tracked in the HE for the entire duration of the simulation and plotted against time in figures 3, 4, 5, and 7 up to 2500 μs after impact. The pressures reached their maximum values within 250 μs for a 45° impact angle and approximately 700 μs for a 14° impact angle. For each impact angle there is very little difference in the peak pressure obtained for different drop heights. However, the pressures for a 45° impact angle were almost double those observed for a 14° impact angle. This is due to a much larger normal component of the stresses during impact and higher initial drop heights. Higher incident angles also results in shorter loading durations. Simulations showed that for a 45° incident angle the billet of LX-10 stuck, pivoted, and then rebounded off the surface of the impact plate. Whereas for the more oblique impact angle, the billet of LX-10 went through and extended slip across the surface of impact plate, while only pivoting slightly before rebounding. The loading duration for a 45° and 14° impact angle simulations were approximately 1600 and 2250 μs respectively.
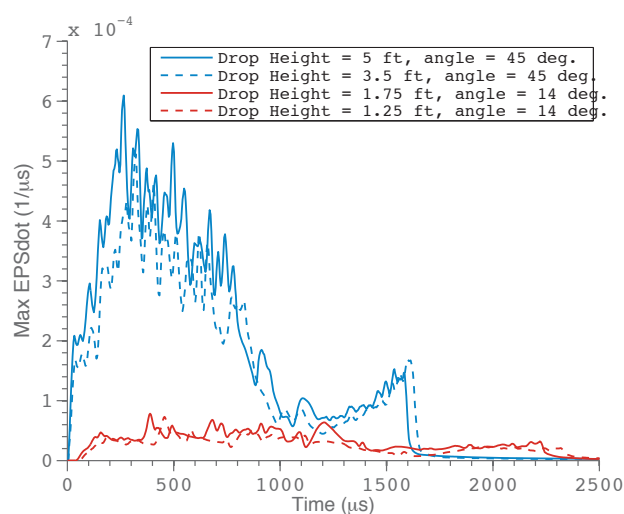
3.2. Strain-Rate and Strain within a Billet of LX-10

The strain rates were on the order of 200 to 500 s^{-1} for the 45° tests and 20 to 50 s^{-1} for the 14° impact tests (see figure 4). In the case of a 45° impact, the durations of highest rate of strain correlated well with periods of initial compression/sticking stage, and transition from pivoting to rebound events. During these events the effective plastic strain rapidly increased to approximately 7% within 400 μs, and 10% by the time the billet rebounded off the impact plate
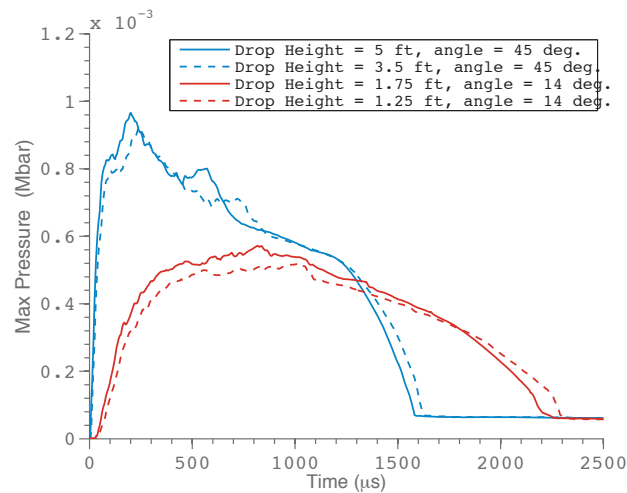
Figure 3. Maximum pressure within LX-10, sampled over the entire billet.

and loading has ceased at 1600 μs (see figure 5). Due to the more oblique angle, the 14° impact tests exhibited far less compression near the contact patch of the billet, had more pronounced skidding, and longer duration of straining, albeit at a lower rate. The strain in this case, reached a final value of approximately 3.5% by the end of the calculations. As with the pressure history plots, there were no significant differences in strain-rates/strain developed for a given impact angle. In figure 6, contour plots of the plastic strain within the billet of LX-10 are shown for a representative calculation from each impact angle at a post-impact time of 1550μs. While the affected region is larger for higher impact angles (and drop heights) the pattern of the stress contours are very similar for each calculation. The regions of highest concentration of strain also accrued the most damage and porosity that may make the explosive more sensitive and results in higher Ign values.

Figure 4. The effects of impact incident angle and drop height on the effective plastic strain rate within LX-10. The plastic strain rate is sampled over the entire billet.
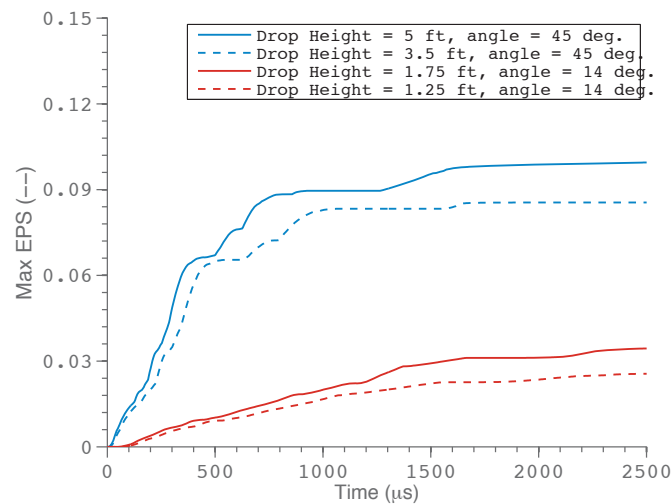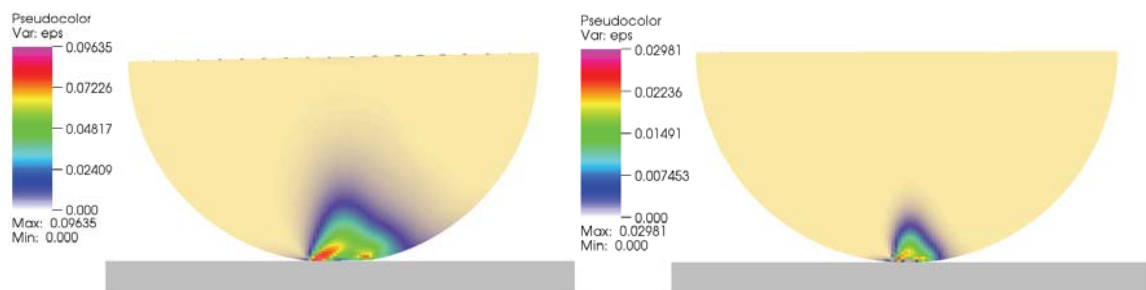
Figure 5. Effective plastic strain within the billet of LX-10 during a skid test and the effects of drop height and impact angle.

### 3.3. Ignition Value within a Billet of LX-10

The history plots for the HERMES ignition parameter value, *Ign*, are shown in figure 7. The value of *Ign* was found to be relatively low (< 2) compared to other non-shock ignition tests that achieved a reaction, e.g., *Ign* in Steven impact tests is approximately 60 [5]. Also, *Ign* is highly dependent on the impact angle with the $45°$ incident angle case having a peak value one order of magnitude higher than the $14°$ case. Peak *Ign* values occur at the contact patch where shear deformation is highest and is a result of the shear-dependence in the ignition criteria.

4. Summary and Path Forward

We found that the incident angle has a much more significant influence on pressure, strain-rate, strain, and ignition states than drop height. The peak HERMES ignition parameter value, *Ign*, is nearly one order of magnitude higher for an incident angle of $45°$ than for $14°$. Peak *Ign* values occur at the contact patch where shear deformation is highest and is a result of the shear-dependence in the ignition criteria. While peak *Ign* values for Steven Tests were approximately

Figure 6. Effective plastic strain contours within the billet of LX-10, 1550 μs after impact. Left, is the strain contour for an impact angle of $45°$ and drop height of 5.0 ft, the right, an impact angle of $14°$ and drop height of 1.75 ft.
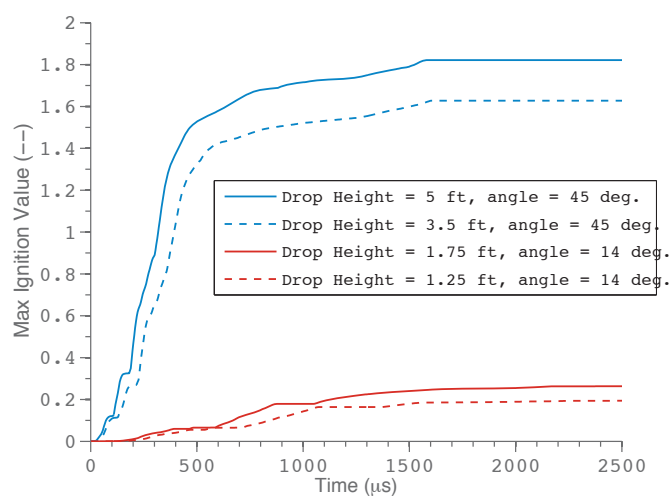
Figure 7. The effect of drop height and impact angle on the HERMES ignition value.

60, the skid test had a much smaller value < 2 for the scenarios considered in this study. The discrepancy in ignition values suggest that grit-explosive interactions play a significant role in skid test response. Since the peak ignition values are much less for the 14° impact angles, the role of the grit may be more important at lower incident angles. Also, in calculations examining frictional effects (not reported in detail here) between the plate and LX-10 billet, doubling the coefficient of friction from 0.4 to 0.8 resulted in no significant increases in the observed pressure, strain-rate, strain, or Ign levels. Future work should include meso-scale calculations to resolve the localized grit interactions that underpins these shear ignition mechanisms.

Acknowledgments

References
[1] Dobratz B M and Crawford P C 1985 *LLNL Explosives Handbook - Properties of Chemical Explosives and Explosive Simulants* (Livermore, CA: University of California)
[2] Reaugh J E 2010 Modifications and applications of the HERMES model *Lawrence Livermore National Laboratory* LLNL-TR-462751
[3] Reaugh J E 2009 Implementation of strength and burn models for plastic-bonded explosives and propellants *Lawrence Livermore National Laboratory* LLNL-TR-412938
[4] Reaugh J E and Jones A G 2010 Mechanical damage, ignition, and burn: Experiment, model development, and computer simulations to study high-explosive violent response HEVR *Proc. of 14th Int. Detonation Sym.* ONR 351-10-185 (Coeur d'Alene, Idaho) p 909
[5] Reaugh J E 2012 unpublished data