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COUPLED EULER-LA GRANGE SIMULATION FOR OVERPRESSURE STRUCTURAL RESPONSE

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Abstract. Accurately modeling blast dynamics is critical in the assessment of structures subjected to blast loading. The current industry standard for modeling blast effects in La Grange based finite element simulations is CONWEP; tabulated pressure data taken directly from blast events. CONWEP is limited, however, and may not always be physically representative of the blast/structural interaction that occurs in the field. Euler hydrocodes provide advantages over CONWEP in that they can capture shock front interaction and model blast surface interfaces with fidelity due to the presence of the working fluid. Euler codes, however, break down over larger time scales due to advection; whereas, Lagrange modeling allows for discrete finite elements with definable boundary interfaces that can be tracked out to longer time scales. Hence, a hybrid approach that couples the Euler blast modeling with La Grange system dynamics is necessary. The objective of this paper is to demonstrate improvements for high explosive overpressure structural response modeling specifically with respect COMP-B high explosive acting upon blasted fragments using a Coupled Euler-La Grange algorithm implemented in Velodyne™. Velodyne results using the Coupled Euler-La Grange algorithm are compared to results from an Euler hydrocode simulation (CTH) and Velodyne simulations using the CONWEP algorithm.

Keywords: Air blast dynamics, Finite element, CTH, Fracture, Fragmentation, High explosive detonation.

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INTRODUCTION

A number of approaches have been studied to computationally model blast effects in literature [1-3]. Classically, a first-principal Euler or Lagrange method would be chosen depending on the individual application; meaning either the mesh was pre-defined or discretely defined, respectively. In general, an Euler domain can accurately propagate a shock wave traveling through a gas, and a La Grange domain can discretely define where interfaces lie between any two materials. The strengths of the Euler method are inherently the weaknesses of the La Grange method, and vice versa.

One approach to bridge this gap was explored with the use of hydrocodes [4,5]. Another approach

was to empirically model the blast with a model such as CONWEP in a first-principles finite element solver [6]. In this approach, blast effects are modeled in a La Grange domain using pressure curve-fits empirically. There is no medium to propagate the blast, but rather an empirically derived analytical formula calculates the initial pressure load on a surface that is in direct line-of-sight and propagates the blast loading onto the surface of a structure. Unfortunately, this model is limited due to empirical calibration to underground mine blasts for the pressure curve-fits, a spherical TNT charge, and prior knowledge of surfaces in direct line-of-sight.

An alternative approach is known as Coupled Euler-La Grange (CLE) which was developed into Velodyne™; Corvid Technologies' in-house,

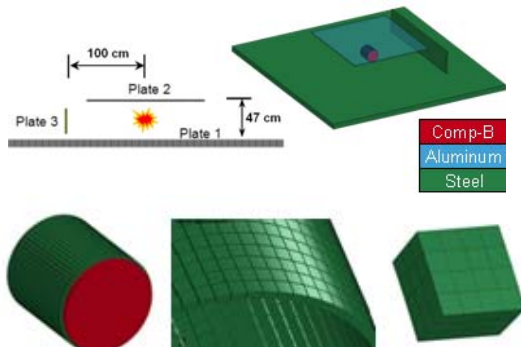


Figure 1. Computational setup for three plate arena.

massively parallel, nonlinear dynamic finite element solver. Previously, this model has demonstrated the importance of wave reflections on the structural response from air-blast loading on an arena of plates [7].

The objective of this study is to further validate the CLE model in capturing the blast effects on structures from pre-defined fragments and non-spherical/non-TNT charges.

COMPUTATIONAL SETUP AND METHODOLOGY

The example setup for this study will be an arena of three plates spaced according to Fig. 1. The three plate arena will have a 350x350x10 cm steel lower plate, and 150x150x2.5 cm aluminum 7075-T6 upper plate, and a 190x43x2.5 cm steel side plate with spacing as indicated in Fig. 1. In the center of the arena will be a 16.7 kg (22 kg TNT equivalent) charge of Comp B oriented to allow radial expansion into the side plate and to be detonated in the center. The charge will be encased by 0.92x0.92x0.6 cm steel fragments ordered 23 lateral x 72 radial separated with ~0.1 cm gap.

For this study the above setup will be modeled

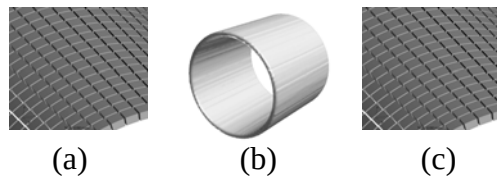


Figure 2. Computational setup for the fragments for (a) CLE, (b) CTH, and (c) CONWEP at 0 ms.

in the following ways: Euler in CTH, La Grange in Velodyne with CONWEP, and Euler-La Grange in Velodyne with CLE. The following assumption was derived for the CONWEP algorithm since there is no medium to drive the fragments in the simulation: the initial radial fragment velocity was chosen based on the sustained average radial velocity of non lower/upper-plate-impacting fragments from the CLE simulation pre side plate impact $\sim 2.2e5$ cm/s.

Since the CLE and CTH calculations can account for the gaseous expansion products from the high explosive it is expected that the fragments will act upon the plates similar to an air-blast.

Euler and La Grange Mesh Domains

The CTH domain was limited by computational resources to an AMR highest level of refinement resolution of 0.4 cm^3 running on 192 processors out to 5 ms with a wall clock time of 64.3 hrs. The Velodyne La Grange domain had an average aspect ratio of 1.78, total of 102,080 elements, and for the CLE algorithm an AMR Euler domain resolution of $\sim 1 \text{ cm}^3$ running on 32 processors out to 5ms with CONWEP and CLE wall clock times of 20.7 & 1.6 hrs, respectively. Fig. 2 shows the initial fragment setup for each calculation.

RESULTS AND DISCUSSION

The fragment velocity magnitude profiles can be seen for the (a) CLE, (b) CTH, and

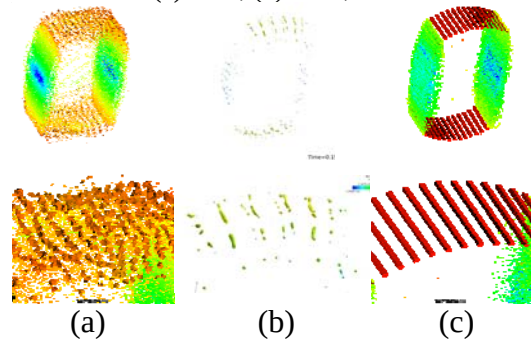


Figure 3. Expansion velocity profile for the (a) CLE, (b) CTH, and (c) CONWEP at 0.15 ms, Color map (online) reads $5.84e5$ cm/s red and $1e4$ cm/s blue on linear scale.

TABLE 1. Fragment kinematics for each calculation at 0.15 ms.

	Total Momentum, g-cm/s	Total Mass, g	Total KE, erg	Total Average Velocity, cm/s
CONWEP	9.43e8	6.41e3	8.79e13	2.84e5
CLE	9.43e8	6.41e3	8.61e13	3.41e5
CTH	7.13e7	3.16e3	4.4e13	2.26e4

(c) CONWEP calculations at 0.15 ms in Fig. 3. Note that the upper and lower plates from Fig. 1 are not shown and located to the left and right, respectively, and fragments have not yet reached the side plate.

At 0.15 ms from Fig. 3, the CTH result indicates fewer fragments with a slower total average velocity as indicated also in Table 1, distributed fairly evenly, and each fragment stress state behaving more like a hydrodynamic fluid in comparison to the other two calculations. The CONWEP result by design cannot influence the fragment velocity and thus the fragments are expanding at the initial radial velocity as seen in Table 1, evenly distributed, and in a pristine unstressed state for the free-expanding fragments as shown in Fig. 3c.

Since both the CLE and CONWEP calculations can account for SPH particle transition and the initial CONWEP calculation radial fragment velocity was derived from the CLE calculation, the momentum and mass are conserved as shown in Table 1, but the kinetic energy can deviate since CONWEP is not directly acting upon the fragments. The CLE result from Fig. 3 indicates that the blast products will distort and accelerate the fragments as expected in an evenly distributed manner. Furthermore, the total fragment momentum, average velocity, and mass are much higher than the CTH result. This effect stems from the advection that occurs in the mixed cells of the CTH Euler domain where deletion of mass can

occur when an object is moving across multiple cells.

The pressure distribution at 0.25 ms is shown in Fig. 4 for the CLE, CTH, and CONWEP calculations with the expanding gases in the CTH and CLE calculations shown in half symmetry.

The CONWEP and CLE calculations have a symmetrical and almost symmetrical pressure profile on the top of the bottom plate, respectively. This is due to the spherical charge assumption in CONWEP, and the fact that the fragments are already pre-formed in the CLE calculation. However, the CTH calculation indicates that the blast wave will propagate much faster down the cylindrical axis of rotation of the HE rather than through the fragments. This is a direct result of the resolution limitation due to resources in the Euler domain for the fragments. Fig. 2 illustrates this effect by which CTH welds the fragments together since the spacing between them is 0.1 cm and the highest AMR resolution is 0.4 cm.

Fig. 4 also indicates that the pressures on the top and bottom plate are highest in the center of the top and bottom plates as expected and are much higher in the CONWEP calculation. The CTH and CLE calculations show about the same peak pressures near the center of the top and bottom plates. Thus, the bending in the top plate is more prominent CONWEP than in CLE.

The damage on the top and side plates can be seen qualitatively in Fig. 5 from the fragments and air-blast or the CLE, CTH, CONWEP calculations

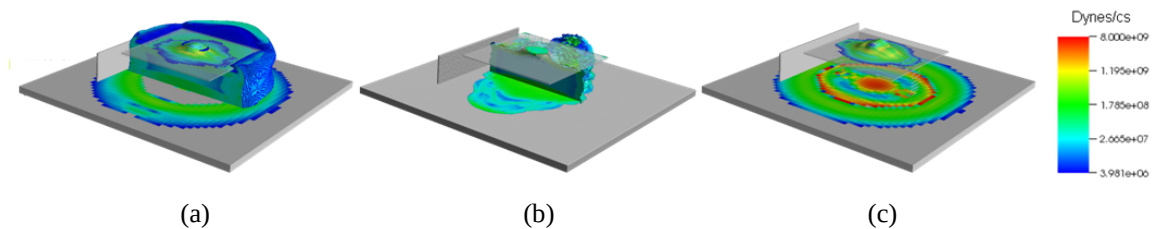


Figure 4. Pressure profile for the (a) CLE, (b) CTH, and (c) CONWEP at 0.25 ms, Color map (Available in online version) reads 8e9 dynes/cs red and 3.981e6 dynes/cs blue on log scale. Top Plate is shown in 63% transparency. The CTH and CLE calculations show the expanding gases in half symmetry for visual purposes only.

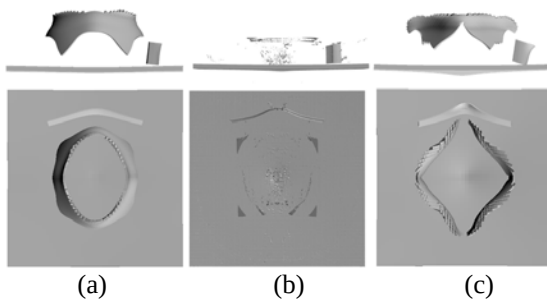


Figure 5. Qualitative plate damage for the (a) CLE, (b) CTH, and (c) CONWEP at 5 ms,

at 5ms. From the side view the CLE and CONWEP calculations show a very deformed top plate and a bottom plate with an indentation forming at the center. The CTH calculation does not capture the top plate bending as it has traversed past the top limit of the domain, but the bottom plate does show the indentation.

The CONWEP calculation over-predicts the indentation effect on the bottom plate and the shape and size of the blast hole on the top plate with respect to CLE. The assumed spherical charge shape of the HE leads to the symmetrical shape of the hole as well as a larger indentation on the bottom plate. Also, since the energy from the blast wasn't consumed in the projecting of the fragments, the hole size overall for the top plate and the indentation of the bottom plate are much bigger. The fragment damage on the top and bottom plates for CONWEP was higher due to the pristine stress states in the fragments before impact.

The side plate damage for the CLE, CTH, and CONWEP calculations indicates significant bending and damage. The CTH result shows an evenly distributed load with respect to the fact that the plate itself does not rotate from Fig. 3b into or out of the page whereas the CONWEP and CLE calculations indicate clock-wise rotation. This is results of the fragments being lost due to advection in the CTH calculation and not properly distributing the load to the side plate. The CONWEP and CLE calculations show this clock-wise bending due to the fragments collecting and gliding along the under-surface of the top plate before eventually striking the side plate more on the upper-portion-middle. The CONWEP

calculation again over-predicts this damage due to the pristine fragments.

CONCLUSIONS

There is a significant difference in how each method attempts to capture the free expanding velocity, distribution of the velocity, and break-up characteristic shape of the fragments. The strengths of the La Grange and Euler methods are coupled together in CLE to produce a balanced method for determining reflected plate damage from any geometrical shaped high explosive wrapped with fragments.

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