# Near-Structure Air Blast Simulations Using Zapotec, A Coupling of CTH and Sierra/SM

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## 1 Introduction

The ability to conduct simulations for air-blasts and their subsequent interaction with structures is vital in the study of a range of security and safety concerns. For significant stand-offs between the blast and the structure, a range of analytic/simplified simulation techniques can provide suitable results, e.g. conwep [1] for simple geometries. However, for blasts which originate close to the structure or with complex geometries, the interaction of the explosive products, air shock, structure geometry, and material failure necessitate the use of more complex computational frameworks. Zapotec, an Euler-Lagrange code which couples the hydrocode CTH with the structural transient-dynamics finite element code Sierra/SM, provides such a framework. This presentation includes a short overview of the Zapotec code methodology, and then compares Zapotec simulations to two simple test series which investigate structural response to explosive detonations with small standoffs where analytic/simplified simulation techniques can fail. The Zapotec simulations compare well to the experimental results in both cases, giving confidence in the use of Zapotec for near-structure air-blast scenarios.

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## 2 An Overview of Zapotec

Zapotec [2] is a coupling between the shock physics analysis package CTH [3] and the structural transient-dynamics finite element code Sierra/SM [4]. Zapotec, CTH, and Sierra/SM are developed at Sandia National Laboratories.

CTH is an Eulerian shock physics code that utilizes a two-step approach for the solution of the conservation equations [3]. The two-step solution approach first involves a Lagrangian step, where the Eulerian mesh is allowed to deform. The Lagrangian step is followed by a remap step. The remap algorithm advects material quantities (i.e., the volume flux, mass, momentum, and energy) from the deformed Lagrangian configuration back into the fixed Eulerian configuration. CTH is widely used in government and industry to model shock phenomena, frequently for explosive detonation.

Sierra/SM is an explicit Lagrangian, finite element code developed for modeling transient solid mechanics problems involving large deformations and contact [4]. The numerical formulation utilizes an updated Lagrangian approach whereby the reference state at each time step is updated to coincide with the current configuration. Although the Sierra/SM formulation accommodates a range of element types, Zapotec supports only a limited set. The supported element types are 8-node hexahedral element and 4-node quadrilateral shell elements. Sierra/SM is also used at a number of government and industry sites to model dynamic structural response.

Zapotec couples these codes by employing a unique explicit volume coupling approach that preserves the independence of the codes for a set amount of time (typically the size of the CTH time step), and then applies corrections to the simulations to synchronize their solutions before starting a new time step. This synchronization step involves two parts (see Figure 1): the insertion of all Lagrangian material into the CTH domain, and the mapping of CTH pressures onto the Lagrangian mesh. In the Lagrangian material mapping step, all previous material corresponding to the last Lagrangian insertion is removed, and the current Lagrangian configuration is re-inserted. Basic information from the Lagrangian solution is mapped into the inserted material, including such quantities as mass and the current stress state. It should be noted that this process resolves any drift in the solution that occurred between the two codes over the time step. To make the Lagrangian side consistent, the CTH stress field from the previous timestep is sampled near the exterior of the inserted material. These sampled stresses are then converted into nodal forces which are applied in the Lagrangian simulation over the timestep. Several different approaches are provided for this sampling to model different interface conditions. For blast-loaded structures, a pressure-only approach is typically used.

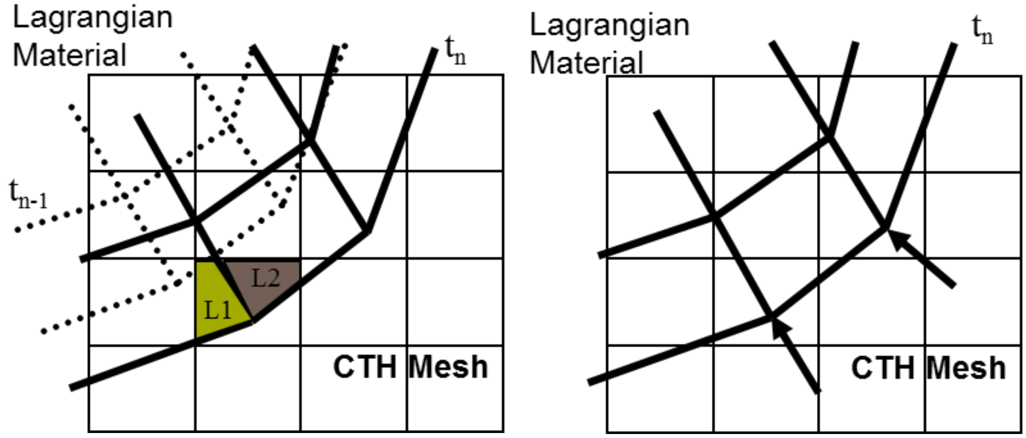


Figure 1. Zapotec coupling Algorithm. Left: Insertion of Lagrangian mesh into CTH; Right: Sampling of CTH cell data to determine loading on Lagrangian mesh

Zapotec has been used for a wide range of problems both at Sandia and externally. It was originally developed for penetration applications, but has also been used for anti-armor simulations, aircraft impacts, blast loading on buried reinforced concrete structures, structural response to air blast, buried mine blast on structure, space launch failure scenarios, and satellite collisions. More recently, it has been used extensively to model hypervelocity impacts to support lethality assessment for the Missile Defense Agency. Various problems in these application sets have been compared to experimental data, with reasonable results.

## 3 Kinetic Plate

To assess the ability of Zapotec to simulate near-structure blasts, a simple experimental series was chosen as a validation exercise. The experimental series was conducted by Pemberton et. al [5], and consisted of a 12.7 cm x 12.7 cm x 1.27 cm steel flyer plate surrounded by a steel collar to prevent the wrap-around of explosive gasses/shocked air. For the case chosen for simulation, a spherical charge of 117.2 g of C4 explosive was detonated 15.2 cm from the plate, and the resulting velocity of the plate was measured using four Photonic Doppler Velocimetry (PDV) sensors.

The Zapotec simulation included the explosive and the air in the CTH domain, while the plate and the collar were modeled in Sierra/SM. The explosive was modeled with a Jones-Wilkins-Lee (JWL) model coupled with programmed burn to model the detonation. The parameters chosen for the JWL model corresponded to the default values supplied within databases included with CTH, which have been validated for a range of cases. Elastic material models were used in the Sierra/SM simulation. The problem utilized symmetry planes to model ¼ of the problem, and mesh resolutions in both CTH and Sierra/SM of 1-2 mm. Mesh resolution studies showed that this resolution was adequate to reach approximate mesh convergence. Simulation stills are shown in Figure 2. The simulation results matched the experimental velocities within less than 4%.

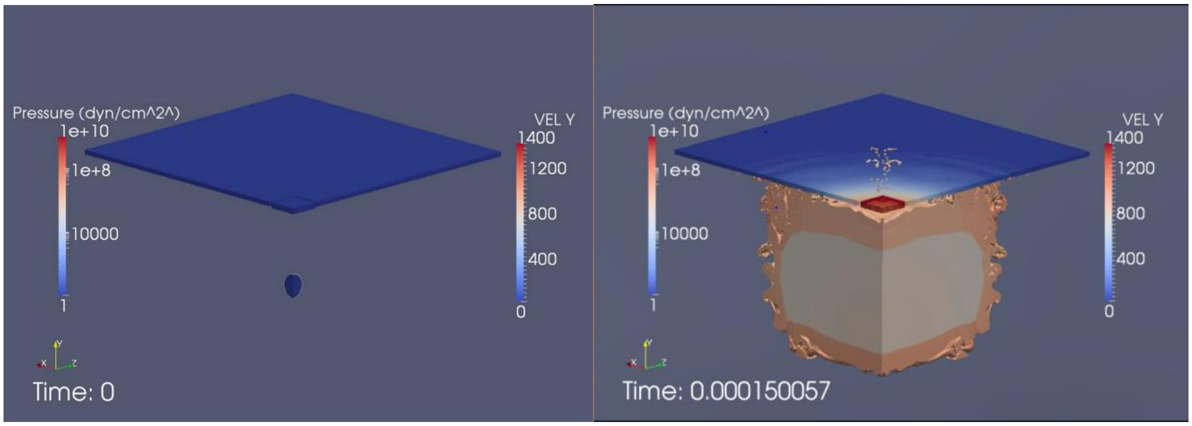


Figure 2. Stills from Zapotec simulation of Kinetic Plate test

## 4 Thin Plate Blast Response

To further explore near-structure air-blast modeling in Zapotec, a second experimental series was chosen [6]; see Figure 3. In this series conducted at Sandia National Laboratories, 44 inch diameter 0.040 inch thick aluminum plates were affixed in a thick steel test fixture and subjected to explosive loadings from the detonation of C4 spheres situated 10 inches from the center of the plate. Explosive masses ranged from 120 to 500 grams. Digital Image Correlation (DIC) was used to measure the deformation of the plates.

These experiments were simulated using Zapotec, with the explosive and air modeled in CTH and the plate and test fixture in Sierra/SM. The simulations employed symmetry conditions to enable modeling of ¼ of the test configuration, and used a mesh resolution of 6 mm in the finite element domain and 4 mm in CTH. A set of mesh resolution studies were conducted, which indicated that at this resolution mesh size had a negligible effect on the results. Due to the thin nature of the aluminum plates, shell elements were used in Sierra/SM, with power-law hardening material models to represent the material response. No failure criterion was used in the plate models, though failure is seen at higher explosive loadings; subsequent analysis indicated that the use of an equivalent plastic strain criterion of 0.18 would effectively predict the onset of failure[6]. Like the Kinetic Plate simulations, the explosive was modeled using a JWL model with programed burn to simulate the detonation process. Initial simulations focused on matching the 120 gram explosive case. The initial simulations required an additional pressure of 10 psi to be applied to the plate in order to capture the center displacement correctly; the additional 10 psi term is hypothesized to correct for errors in the JWL fits used for the explosive. Subsequent simulations of the higher charge masses yielded accurate predictions of the experimental results. See [6] for more details on the numerical comparison.

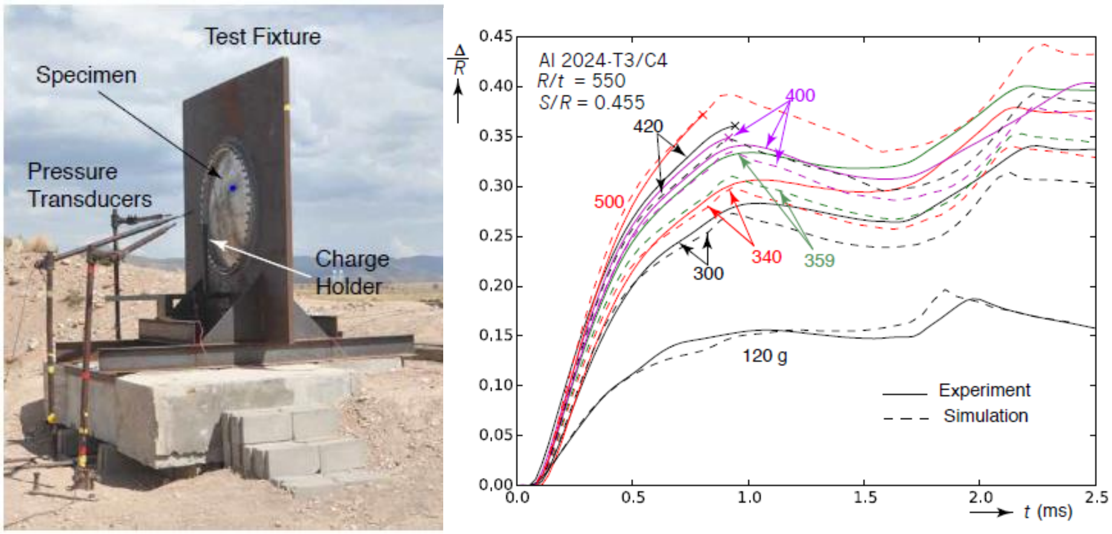


Figure 3. Simulation of near-field blast on thin plates. Left: Experimental configuration; Right: Comparison of center deflection of plate in simulation and experiment for differing charge masses

## 5 Conclusions and Final Remarks

The Zapotec simulations described within this presentation show good comparison to experimental results of the structural deformation for specimens subjected to near-field blasts. Zapotec has since been used to model structural blasts on more complex bodies, with similar quality results. This represents an important tool in predicting structural blast response for critical structures.

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