Key Parameters in Blast Modeling Using 2D to 3D ALE Mapping Technique

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Abstract

A numerical simulation is conducted to model the explosive detonation and blast wave propagation in the open air field. The mesh size and boundary conditions as well as size of air domain are the sensitive variables which may significantly affect the predicted pressure wave magnitude and rising time in blast simulations. The current approach focuses on determining the optimal key parameters to predict the blast wave accurately. A 2D to 3D mapping is performed to save the computational time. The blast induced high pressure waves are generated using the Arbitrary Lagrangian-Eulerian (ALE) formulation in the 2D domain and then mapped into a 3D space. The simulation results show that the aforementioned parameters govern pressure wave form in both 2D and 3D cases. A two-step mesh sensitivity study is performed: A parametric study is first conducted in the 2D air domain and then followed by a second one in the 3D domain while using 2D to 3D mapping. After that, as a case study in the biomedical applications, an anatomically detailed pig head finite element model is integrated with the 3D air domain to calculate the pressure gradient change inside the brain due to blast wave. The model predictions are compared with the experimental data and it has shown that the modeling strategy used can capture the biomechanical response of the surrogate with reasonable accuracy and reduced computational cost.

Keywords: *Blast simulation, Arbitrary Lagrangian-Eulerian (ALE), 2D to 3D mapping, mesh sensitivity, LIS(Lagrangian-in-solids) coupling, Intracranial pressure*

Introduction

Blast related finite element simulations are used extensively to simulate pressure waves generated by detonation of improvised explosive devices (IEDs). The physics behind the generation and propagation of blast waves are well understood, and incorporated successfully in general purpose non-linear analysis codes e.g. LS-DYNA®. Blast wave pressures have been modeled using tools such as CONWEP(CONventional WEApons),MMALE(Multi-material Arbitrary Lagrangian-Eulerian) solvers using complicated equation of state(EOS) for different explosives in LS-DYNA. The approach involves modeling of the explosive, transmitting media for blast wave and the target interaction with blast wave through coupling algorithms. These numerical simulation techniques have been used extensively [1-4] due to high cost and instrumentation complexities involved in blast experiments. The blast computational studies have been proved as a useful tool to minimize the number of trials and to explore the parameters which are difficult to measure in the physical tests.

Mesh density, boundary conditions, constitutive material model and equation of state (EOS) are the key factors to be considered while validating finite element blast simulations using MMALE approach. In the current research, a mesh convergence study is performed to find the optimal mesh density for the air as well as for the explosive material models.

Furthermore, Fluid-structure Interaction (FSI) between the blast waves and the target lagrangian geometry can be studied using the coupling algorithms available in LS-DYNA. Such an effort is made as a parametric study for the biomechanical responses in a pig head model under air shock loading.

The following sections describe the technique used to validate the simulation results with the theoretical calculations for the blast in open air environment and the FSI of the blast wave with lagrangian mesh of pig head skull and brain.

Materials and Methods

*In this study, numerical models were developed to simulate the air blast wave propagation using the Arbitrary Lagrangian-Eulerian (ALE) formulation. Since the air domain has a large number of elements, a 2d to 3d mapping technique was used to save the computational time without reducing the accuracy. The idea of this technique is to simulate the shock wave in the 2D air domain during its propagation phase before the shock front reaches the target. At the end of this phase, the results in the 2D domain are mapped into 3D air mesh. The air domain was modeled with ALE2D elements with *NULL material and the C4 explosive was modeled with ALE2D elements with*MAT_HIGH_EXPLOSIVE_BURN material card available in LS-DYNA material library. The equation of state (EOS) for air and explosive were LINEAR_POLYNOMIAL and JONES_WILKINS_LEE (JWL), respectively.*

Generally, linear polynomial equation of state can be used to define the characteristics of the fluid. Currently, a simplified linear polynomial equation of state was used to model the behavior of air. The pressure is defined as a function of internal energy per unit volume, E,

$$P = C_0 + C_1\mu + C_2\mu^2 + C_3\mu^3 + (C_4 + C_5\mu + C_6\mu^2)E$$

where C_0, C_1, C_2, C_3, C_4, C_5 and C_6 are constants.

$$\mu = \frac{\rho}{\rho o} - 1$$

where, ρ=current density, ρ_0= initial density

The JWL equation of state defines the pressure as a function of the relative volume, V and internal energy per unit volume, E, which can be written as

$$P = A\left(1 - \frac{\omega}{R_1 V}\right)\exp(-R_1 V) + B\left(1 - \frac{\omega}{R_2 \omega}\right)\exp(-R_2 V) + \frac{\omega}{V}E$$

*where A, B, R_1 and R_2 are the constants that depend upon the characteristics of the explosive used. The keyword *INITIAL_DETONATION defines the exact location of the explosive detonation. The parameters in the material model and EOS were taken from the available literature [5] as shown in Table 1. The two dimensional model setup for blast loading is shown in Figure 1.*

A mesh sensitivity study was performed to determine the optimum size of the elements in the air domain to validate the model with the theoretical calculation using Conwep. Different mesh sizes of 6.4mm, 4.8mm, 2.4mm, 1.2mm and 0.9mm were tried to see the effect of varying mesh density on the pressure wave magnitude. Figure 2 shows the result of mesh sensitivity study. It can be concluded that the solution converges at the element size of 0.9mm in the current case. The time history plot of blast overpressure is shown in Figure 3. The peak blast overpressure and the duration are in good agreement with the theoretically calculated blast incident pressure from Conwep. The pressure wave transmission in the air domain is shown as a sequence of blast event at different time steps in Figure 4.

Component	*UNIT SYSTEM(kg,mm,ms)*						
Air	**MAT_NULL*						
	RO	*PC*	*MU*	*TEROD*	*CEROD*	*YM*	*PR*
	1.13E-09	*0*	*0*	*0*	*0*	*0*	*0*
	**EOS_LINEAR_POLYNOMIAL*						
	C0	*C1*	*C2*	*C3*	*C4*	*C5*	*C6*
	0	*0*	*0*	*0*	*0.4*	*0.4*	*0*
	E0	*Vo*					
	2.50E-04	*1*					
Explosive	**MAT_HIGH_EXPLOSIVE_BURN*						
	RO	*D*	*PCJ*	*BETA*	*K*	*G*	*SIGY*
	1.60E-06	*8193*	*28*	*0*	*0*	*0*	*0*
	**EOS_JWL*						
	A	*B*	*R1*	*R2*	*OMEG*	*E0*	*V0*
	609.772	*12.95*	*4.5*	*1.4*	*0.25*	*9*	*1*

Table 1: Parameters for material models and EOS

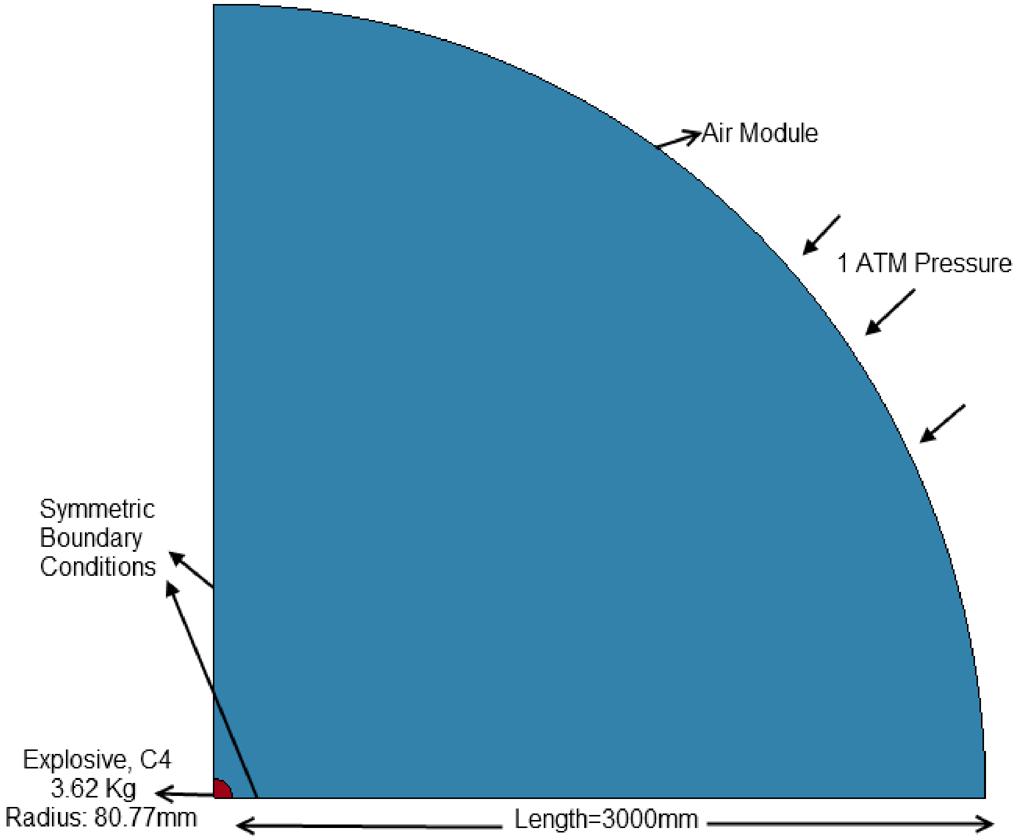


Figure 1. The model setup for a 2D air domain and charge

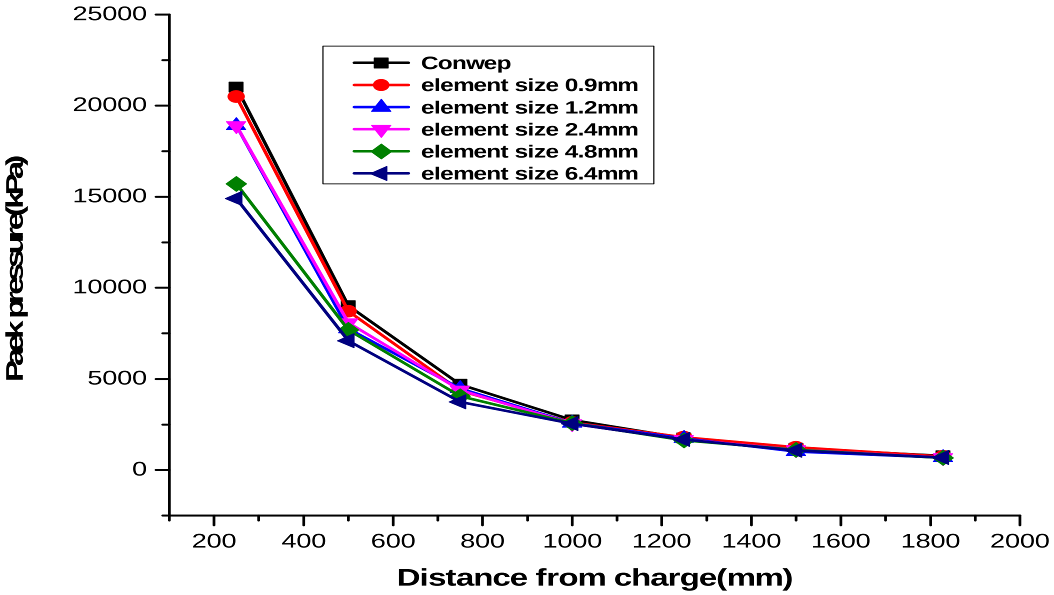


Figure 2. Comparison of the model predicted and theoretically calculated peak pressures at different mesh sizes

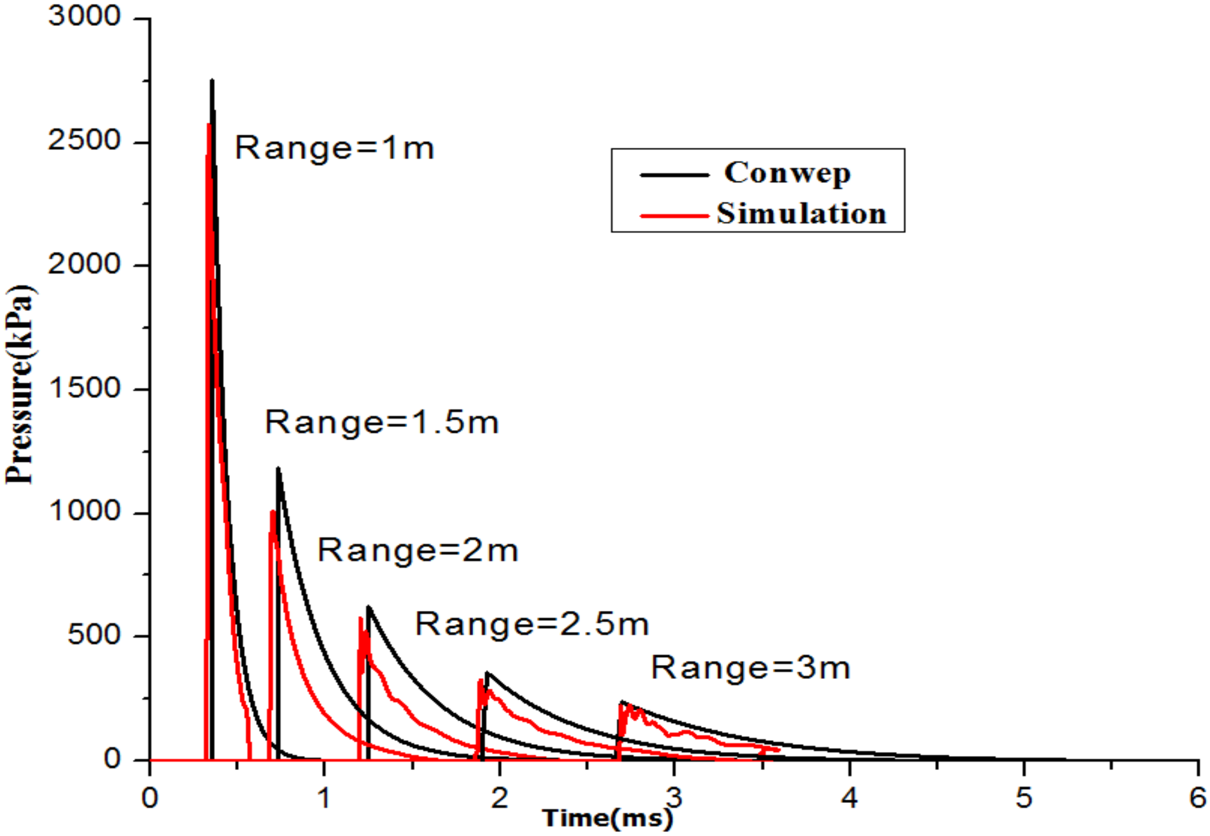
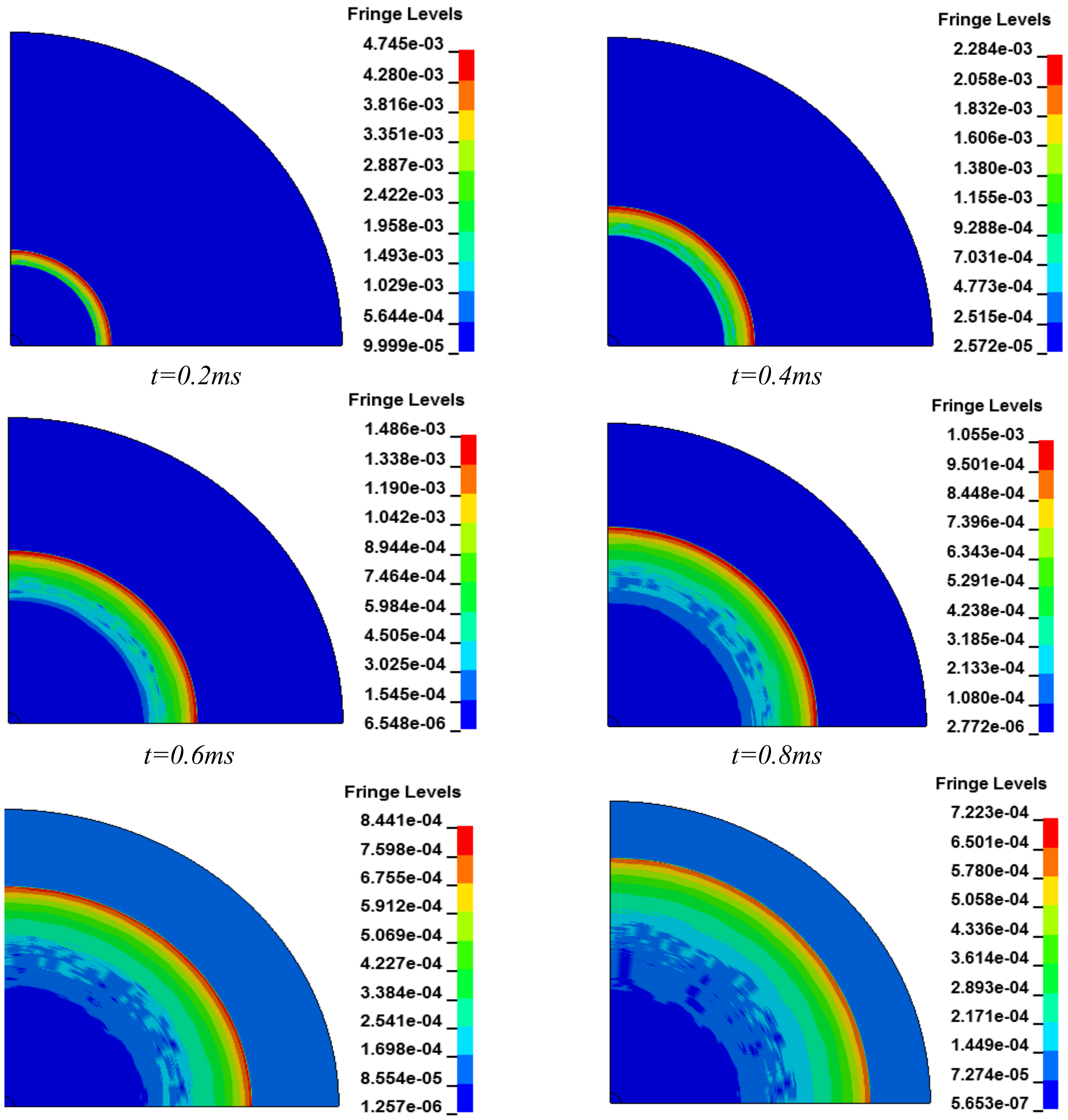


Figure 3. Comparison of the model predicted and theoretically calculated pressure waves



t=0.2ms *t=0.4ms*

t=0.6ms *t=0.8ms*

t=1.0ms *t=1.2ms*

Figure 4. Pressure contour of the blast wave in the air domain at different time steps.

Mapping Technique

Since modeling the three dimensional air space requires a large number of elements which in turn makes the model bulky and costly. A 2d to 3d mapping technique was used to save the computational time without reducing the accuracy. The idea of this technique is to simulate the shock wave in the 2D air domain during its propagation phase before the shock front reaches the target. At the end of this phase, the results in the 2D domain are mapped into 3D air mesh and then the shock wave is coupled with the target in the 3D domain. Since simulations with 2D mesh are much faster than in the 3D mesh, the computational cost can be significantly reduced in this *way. Figure 5 shows that pressure profile at the end of 1.5ms has been successfully mapped to 3D air domain at 1.5ms.*

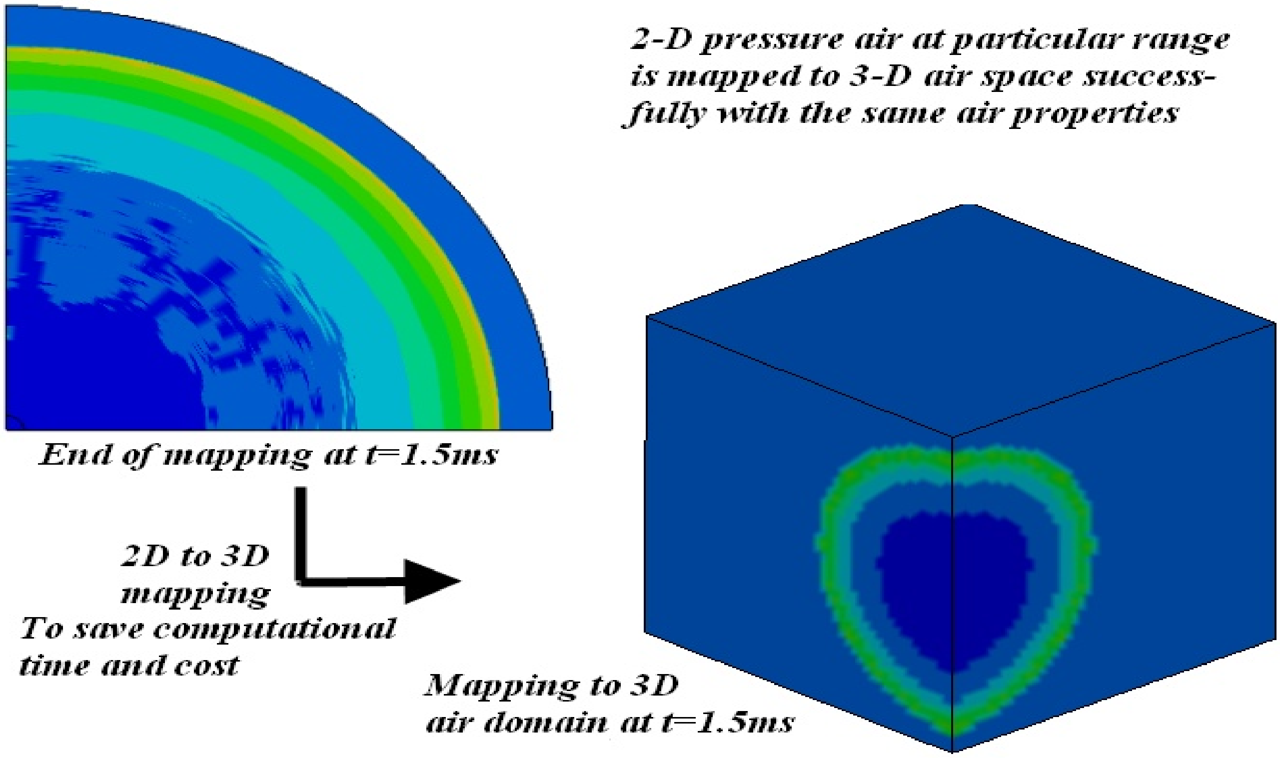


Figure 5. The procedure of 2D to 3D mapping

As an application in blast modeling techniques in biomedical engineering, numerical simulations have been used to study the effect of improvised explosive devices (IEDs) on the human body especially on the head region. FE models of different type of biomechanical surrogate such as pig head and rat head have been developed and their interactions with blast waves have been studied in terms of pressure, stress and strain responses [6,7]. Previous efforts have been made to study the effect of blast wave on head in the shock tubes and their numerical simulations have been successfully conducted. Relatively fewer studies have been focused on the open field blast environment.

Fluid-structure Interaction (FSI)

*Once the pressure wave is successfully mapped to 3D air domain, a parametric study is conducted with a pig head model to examine the bio-mechanical responses inside the brain. The shock wave is interacted with the target, i.e. the pig model in the 3D domain using the fluid/solid coupling algorithm. The *CONSTRAINED_LAGRANGE_IN_SOLID formulation available in LS-DYNA was used to model the coupling between the shock wave and the biomechanical surrogate. The material properties of pig skull and brain tissues were taken from the published literature [8, 9]. Figure 6 illustrates the blast impact simulation setup with the pig head and brain model included.*

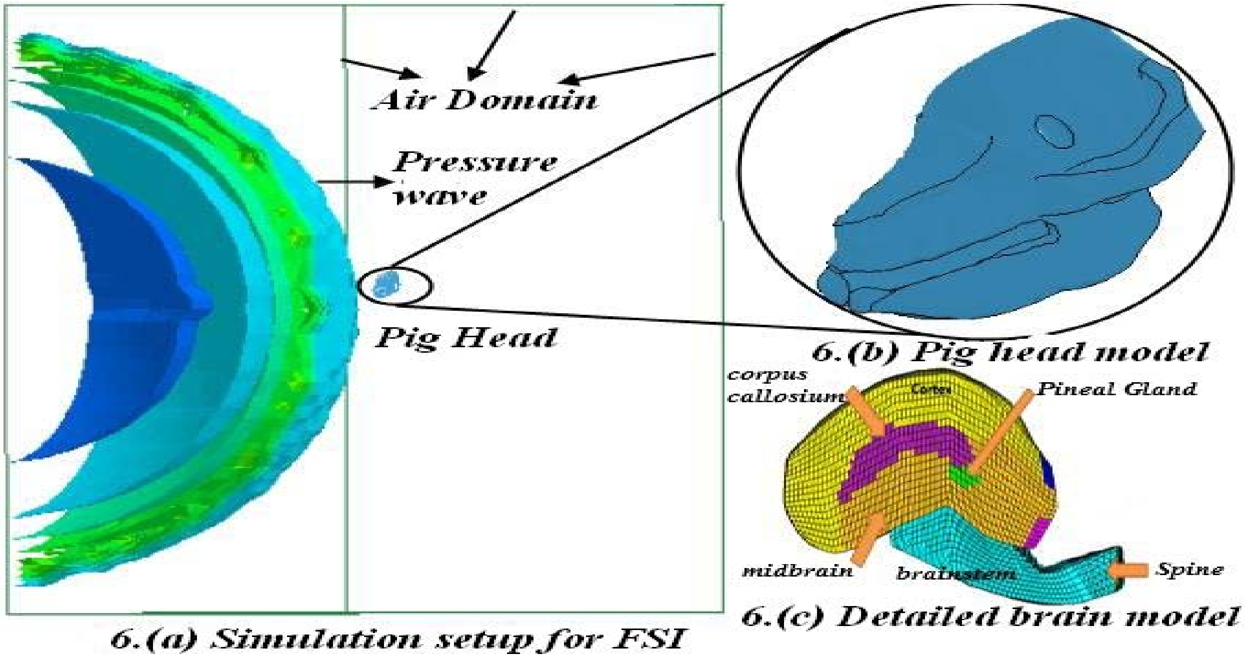


Figure 6. (a) Model setup, (b) Pig head model, (c) Detailed brain model

The biomechanical responses of the pig head in terms of regional distribution of intracranial pressure were compared with the preliminary experimental data at peak incident pressure level of around 300 kPa. The predicted intracranial pressures and the experimental pressure magnitudes inside the pig brain are shown in Table 2 and the trends are similar to data available in literature [6].

Sr No.	*Air pressure (kPa)*	*Intracranial pressures(kPa)*					
	Incident Pressure	*Frontal*	*Parietal*	*Left Temporal*	*Right Temporal*	*Occipital*	*Center*
1. Experiment	*324.2*	*336.0*	*638.4*	*442.1*	*561.4*	*377.3*	*291.3*
2. Experiment	*286.0*	*237.0*	*248.7*	*208.7*	*217.4*	*215.8*	*251.5*
3. Simulation	*298.0*	*503.0*	*444.0*	*419.0*	*338.0*	*386.0*	*406.0*

Table 2 Comparison of model predicted and measured incident pressure and intracranial pressure magnitudes

Currently, due to limited experimental data sets and scattering in the available data, the simulations results for biomechanical responses are not in a good correlation with the test results, but more comparisons will be made once new experimental data will be available.

Conclusions

Simulation results indicate that the explosion within the open filed can be described using the multi material arbitrary Lagrangian-Eulerian formulation combined with 2D to 3D mapping *technique. The FE model predicted blast pressure-time histories were in reasonable agreement with the theoretically calculated results. From the pig head parametric studies, it has been shown that the interaction between the explosion product and the pig head can be modeled by an ALE/Lagrangian coupling algorithm, although further study is needed for better validation of biomechanical responses inside the pig head.*

Acknowledgement

This research was supported by MRMC Contract No. W81XWH-12-2-0038, US Army and the Bio-engineering Center at Wayne state University. The financial support is gratefully acknowledged.

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