Numerical Investigation of the Impact of Blast Wave on the Obstacles Using Moving Mesh Model

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Abstract

The safety assessment and disaster predicting methodologies of explosion play an important role for evaluating explosion-related disasters. This study describes application of a Computational Fluid Dynamics (CFD) methodology to the simulation of interaction between blast wave and the movable obstacle. The proposed physical model for two- and three-dimensional, inviscid and unsteady flows used the Euler equations that were solved with the time-implicit formulation. A dual time-stepping, multi-stage scheme was used to produce accurate results for pure convective processes. For the spatial discretization, the second-order upwind numerical algorithm was used and the physical quantities at cell faces were computed using a multidimensional linear reconstruction approach. Dynamic mesh model was then applied to the domain of study where the shape of the domain is changing with time due to the motion on the domain boundary. In this study, the movement of bodies and propagation of blast wave are presented. In addition, the qualitative analysis of the complex aerodynamic phenomena with isopynics, pressure contours, and velocity vectors are described.

Keywords：CFD, blast wave, dynamic mesh model

1 Introduction

Blast effect is the destructions or damages to structures and personnel by the force of an explosion on or above the ground surface. An incident blast wave impinges on a structure; then the wave is reflected and reinforced, producing what is known as reflected pressure. Recently, researchers have utilized both experimental and numerical approaches in an attempt to clarify the physics of the blast phenomena, display the associated visual effects, and develop techniques to predict the likely effects of blast waves. Measurements [1, 2] of the strength of blast wave under conditions of the free-air or surface burst explosions have been carried out during the past several decades. Tai et al. [3, 4] have investigated the interactions and effects of blast wave with Computational Fluid Dynamics (CFD) method. Some moving mesh models [5, 6] have been proposed for solving the realistic problem in body movement and deformation. Meanwhile, Löhner et al. [7] refined the CFD code – FEFLO – to improve the capability which included adaptive, unstructured gridding, solvers, mesh movement techniques, etc. Baum et al. [8] applied a coupled CFD and Computational Structural Dynamics (CSD) methodology to the simulation of blast waves generated by bare explosive charges in a test facility with rigid and deformable walls.

The CFD method has achieved a significant progress and is considered to be very close to its mature stage in the computation of flows at designated conditions. However, the CFD is still far from being a mature tool to deal with the problems with geometrically complex and largely moving and deforming body. In this study, an Euler solver with moving mesh model was applied to simulate the unsteady flows through the interaction between the blast and solid bodies. In addition, for this study a two-dimensional rectangular bar was simulated to demonstrate the application of the dynamic mesh method. Then the three 3-D geometries, a concave block, and a four-wheeled armored vehicle were simulated and analyzed. The numerical method presented in this paper utilized the cell-averaged control volume scheme with the intent to predict numerically the blast effects – including the wave development, aerodynamic phenomena, and shifted movement of obstacles –using the dynamic mesh model.

2 Methodology

The present numerical method utilizes the cell-averaged control volume scheme. The dynamic mesh model [9] employed in this study was used to study the flows where the shape of the domain changes with time due to the motion on the domain boundary. A six-degree-of-freedom solver was used to model flows where the shape of the domain changes with respect to the motion on the obstacle boundaries. Translational and angular motions of the center of gravity were calculated from the object's forces and moments balance on a solid body. The computational meshes were generated with the GAMBIT mesh generator. The angular and translational velocities were then used in the dynamic mesh calculations to update the rigid body position. In addition, remeshing method was used for local remeshing, where the agglomerated cells are adjacent to the moving face zones, based on the cell skewness, minimum and maximum length scales together with an optional sizing function.

3 Results and Discussions

In this study, a two-dimensional rectangular bar was simulated to demonstrate the application of the dynamic mesh method. Then the three 3-D geometries, a concave block, and a four-wheeled armored vehicle were simulated and analyzed. The initial pressure and temperature of the simulated blast source were assumed to be at constant values while the ambient region was at 1 atm and 300 K.

3.1 Two-dimensional flow field of rectangular bars

A two-dimensional schematic illustration with boundary conditions of rectangular bar is displayed in Fig. 1, where the rectangular bar was assumed immovable (for Case1) and movable (for Case2), respectively. The initial non-dimensional pressure (P/P_∞) and temperature (T/T_∞) of the simulated blast source were assumed to be at 100 and 1000, respectively. Fig. 2 displays the deformation of meshes from horizontal static-state to rotating movement at 0.8, 1.4 and 2.0 ms. The meshes in the region between interface (indicated by the red line) and bar continually keeps the same relative positions during the movement of the bar. While the bar rotates clockwise, the meshes enlarge on the left side and under the interface along the rotating track, as shown in Fig. 2(b) and 2(c). Meanwhile, these meshes deform around the interface while the bar moves and pushes this region. Development of the wave pattern with isopynics contours at 0.6, 1.2, 1.8 and 2.4 ms is presented in Figs. 3. Initially, the blast wave (BW) ejects from the assumed rectangle source and propagates radially outward, as shown in Fig. 3(a). While the blast wave impacts on the surface of horizontal static bar, it breaks into two parts and the bar rotates clockwise. The reflected wave (RW) is generated under the bar. Meanwhile, the blast wave moves along the surface under the bar and forms a Mach stem (MS). The air above the bar is pushed and generates a compressed wave (CW), as shown in Fig. 3(b). The blast wave interacts with the CW on the left side of the bar. On the right side, the sudden clockwise movement of bar pushes the air and forms a CW, as shown in Fig. 3(c). At 2.4 ms, the blast wave still pushes the bar and interacts with the CW on the right side. The moving bar squashes the blast wave while the wave passes by the left end of the bar and causes the pressure to increase, as shown in Fig. 3(d).

3.2 Three-dimensional concave block

A three-dimensional interacting flow field between a blast wave and a concave block proceeds with dynamic mesh model to predict the movement and blast effect. The schematic illustration with boundary conditions is displayed in Fig. 4. In this study, the unstructured meshes system was used, as shown in Fig. 5. To combine the dynamic mesh model, the interface (indicated by the red line) was set around the body. Initially, the blast source with high pressure and temperature air, where P/P_∞ =100 and T/ T_∞ =1000, is located under the left side of block. Two images with pressure contours on the block surface and velocity vectors on the Y-Z cross-section at 5.0 and 15.0 ms are shown in Figs. 6. While the blast wave bursts out and impacts on the block, the block is pushed up and moves clockwise. At 5.0 ms, the blast wave travels to the left top region of block and generates a vortex. Meanwhile, the reflection from the bottom surface and movement of block generate two vortexes, as shown in Fig. 6(a). Furthermore, the blast wave not only pushes on the left side of block but also hits on the concave surface and thus increases the impacting intensity of block, as shown in Fig. 6(b). In both images, we can find the compressed effect is formed on the right side of block while the block rotates. Finally, by observing the behaviors of the blast wave propagation and block movement, this simulation is close to the realistic situation in qualitative analysis.

3.3 Three-dimensional four-wheeled armored vehicle

Fig. 7 displays the schematic illustration of the simulation domain that includes a blast source and a three-dimensional four-wheeled armored vehicle. The cuboid blast source was set under the front chassis. Its initial non-dimensional pressure and temperature were assumed to be at 1000 and 333, respectively. To describe the phenomena of flow field and effect of vehicle more clearly, pressure contours on the vehicle surface and on the cross section near ground, and velocity vectors on the X-Y (Z=0.52) and X-Z (Y=0.45) cross sections in the duration at which the vehicle is impacted are presented in Figs. 8. The series images are at 4.0, 6.0 and 8.0 ms respectively, as shown in Figs. 8(a)~8(c). We can find the general physical phenomena as described in the concave block case above. The main affected area by blast wave is on the front chassis during the blast wave burst and the wave propagates radially. Because the blast source was assumed to be the air species only, the intensity of the blast dissipates rapidly without any chemical reaction after it bursts instantaneously from the source. The results obtained from this study indicate that the location of blast source is the key factor that influences the impact on and interaction with the vehicle. In addition, the shape of hull also relates to the blast effect and to the rotation of the body impacted.

4 Conclusions

In this paper, the numerical method with unsteady-state and dynamic mesh system has demonstrated to provide a suitable tool to simulate the more realistic and complicated engineering problems in the predictions of blast wave. For the simulations performed in this study, the results present special properties of the blast waves via the flow structure and the phenomena of impacting, interaction, and reflection. Refinement of mesh and code validation will be studied in the future work. Certainly, the difference of volumes of meshes needs to be improved to result in a more precise simulation in the entire domain. Meanwhile, the chemical reaction should be added in the simulation to determine the more realistic physical phenomena.

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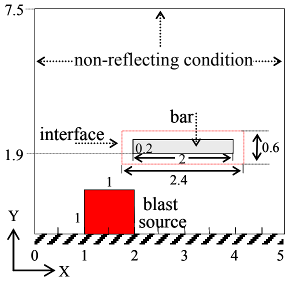
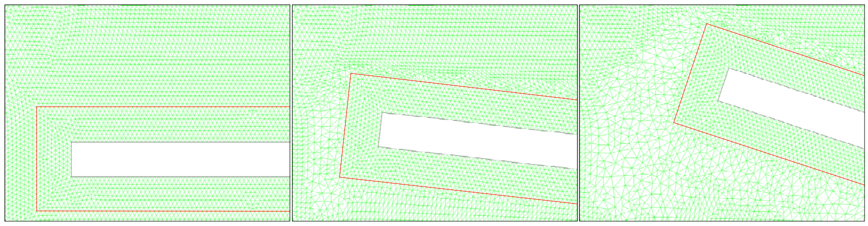
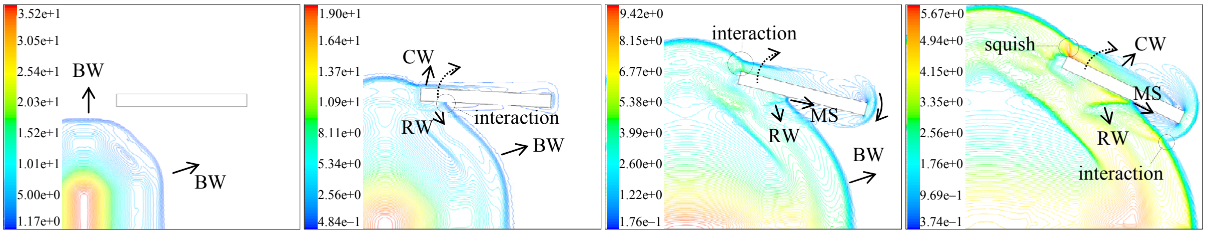


Fig. 1 A two-dimensional schematic illustration of rectangular bar



(a) 0.8ms (b) 1.4 ms (b) 2.0 ms

Fig. 2 The deformed meshes of a two-dimensional bar at different time.



(a) 0.6 ms (b) 1.2 ms (c) 1.8 ms (d) 2.4 ms

Fig.3 The isopynics contours at different time during the bar pushed by the blast wave.

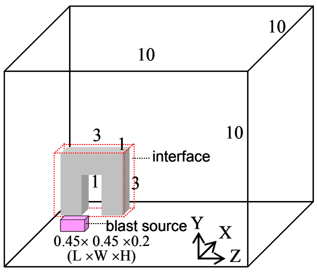


Fig. 4 A three-dimensional schematic illustration of a concave block.

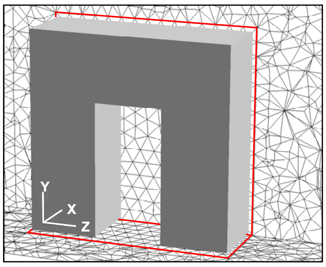
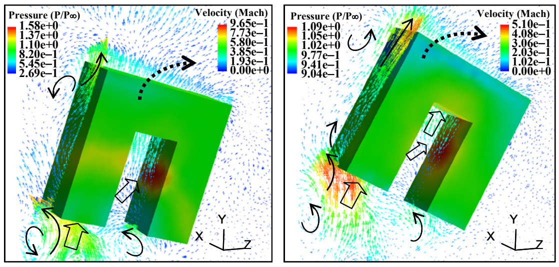


Fig. 5 The unstructured mesh system in the calculational domain of a concave block



(a) 5.0 ms (b) 15.0 ms

Fig. 6 The moving concave block with pressure contours and velocity vectors.

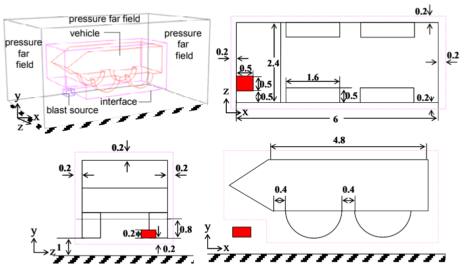
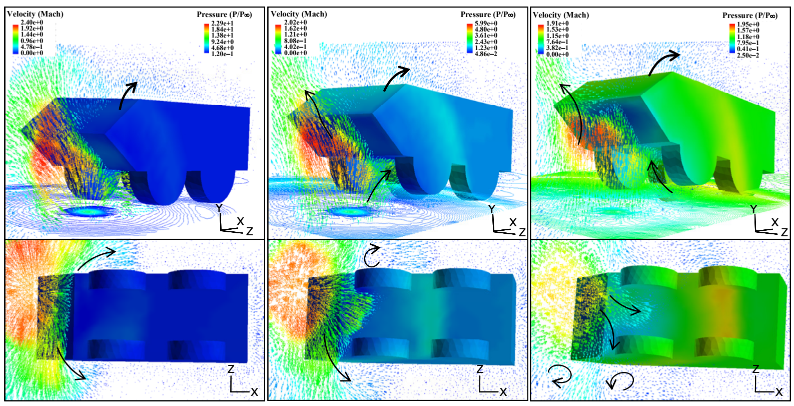


Fig. 7 A three-dimensional schematic illustration of a wheeled armored vehicle.



(a) 1.0 ms (b) 4.0 ms (c) 7.0 ms

Fig. 8 The pressure contours and velocity vectors of the wheeled armored vehicle.