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A new method for very fast simulation of blast wave propagation in complex built environments

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The paper is concerned with the development of a fast, accurate, and versatile method of simulating the propagation of a blast wave within complex built environments. An ability to complete a simulation of the propagation of a blast wave within a few seconds or minutes is an essential tool for evaluating its impact on key structures and to find an optimal design for components such as blast barriers. The need for rapid simulation is made more important by the many uncertainties that exist about the blast environment, such as the size and location of a bomb and the status of temporary obstacles to the blast wave (including whether blast doors are open or closed). Significant uncertainties require a simulation to be executed many times using, for example, Monte Carlo sampling to derive an accurate statistical assessment of the impact of the blast. Rapid simulation would also allow engineers to use immersive visualization techniques, such as virtual reality, to gain better insight into the behaviour of a blast wave and the way it interacts with the built environment.

Existing methods of modelling the propagation of a blast wave fail to satisfy all of the above requirements. Direct prediction models (such as the neural network-based estimators of Remennikov and Rose (2007), or Flood et al. (2009)) are very fast and can be accurate, but are limited to estimating blast pressures for simple building geometries. Ray-trace models (see, for example, Frank et al. (2007a, 2007b)) are also fast and can in principle consider complex building geometries, but are unable to model diffraction of a blast wave around corners and are thus limited in accuracy for all but the simplest of environments. Computational fluid dynamics (CFD) simulations can model complex geometries with acceptable accuracy, but are extremely slow taking several days or even weeks to execute a single three-dimensional simulation. Increasing the mesh size in a conventional CFD simulation can reduce processing time significantly, but seriously compromises the accuracy of results (Löhner et al. 2004).

An alternative method proposed here is to use a simulation approach implemented within a coarse spatial and time framework, where the mesh elements and time steps are orders of magnitude larger than those used in conventional CFD simulations. An issue with this approach, however, is that the driving equations upon which CFD simulations are based are only accurate for very small spatial and time differences. In addition, the wavelength of a blast wave is sufficiently narrow that at any point in time it may only intercept a few (if any) points on a coarse mesh, making it impossible to apply standard CFD algorithms. The proposed solution to these problems is to predict the time until arrival of a wave (and its corresponding form and amplitudes) for all mesh points immediately in advance of the wave. These predictions would be computed from the descriptors of the wave at the mesh points trailing the wave, and the simulation would advance by jumping to the next time when the wave arrives at a mesh point (similar to next-event jumping used in discrete-event simulations). Predictions of the wave descriptors at a mesh point will be made using empirical modelling techniques, including artificial neural networks, trained using data collected from conventional CFD models.

Preliminary research suggests that the reduced computational load resulting from this method will allow simulations to be executed several orders of magnitude faster than conventional CFD methods. The number of elements that would have to be recalculated at each step in a conventional CFD simulation will be in the order of 2,500 for each square meter of a two dimensional model, and 125,000 for each cubic meter in a three dimensional model. In contrast the proposed coarse grain modelling approach would require just one element to be recalculated at each step in a simulation, independent of model size. Moreover, a CFD simulation will require in the order of 100 times more time steps to advance a simulation the same distance as the coarse grain approach. There is some significant computational disadvantage to the coarse grain approach in that it requires a lot more processing to recalculate the state of one of its elements (perhaps in the order of 600 times), but the net performance indicated is that a three dimensional CFD simulation that takes 1 year to process may be completed by the coarse grain model in just 30 seconds.

Such an increase in performance would certainly make three dimensional simulation of blast wave propagation in a complex built environment accessible. However, the other question to be answered is the accuracy of the predictions. This is a more difficult question to address than that of processing speed without actually performing a comprehensive set of customized experiments.

The next stage in the project is to implement the coarse-grain model and validate it performance for a comprehensive range of complex building geometries. Performance will be measured in terms of processing speed and accuracy.

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