A SCALED AIR BLAST MODEL FOR HIGH ALTITUDES

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ABSTRACT

Based on Sachs scaling, an engineering computational model on air blast wave at high altitudes is presented in this paper. The model is built on analysis from numerical simulated pressure time data of shock wave in air. The model describes the peak overpressure, impulse, and typical time of the shock wave with new parameters. Comparison of pressure, density and velocity configuration for the different altitudes shows that the present engineering model can give consistent results with the numerical code. At last the scaled peak overpressure and the scaled impulse figure for the different altitudes are given for convenience of engineering application.

Keywords: blast wave, overpressure, numerical simulation.

1 INTRODUCTION

Impact loading of air blast is important in the research of defending safeguard. The model of air blast wave usually describes the rules of overpressure changed with time with respect to the scaled distance after an explosion in air of equivalent TNT explosive. Several blast wave models have been presented based on experiments or numerical simulations [1]–[4]. With analysis on numerical simulated pressure time data, the author of this article have presented a simple and practical air blast model which can nicely describes blast wave for a long range of scaled distance [4]. But the model cannot be used to analysis blast wave problems at high altitudes, so the motivation of the paper is to develop a new model for explosion at high altitudes.

The second part of the paper introduces the ambient conditions, such as value of pressure, density and the sound velocity. Based on Sachs scaling [1], several old engineering computational equations are revised with new parameters. After the parameters are calibrated based on data from numerical simulations some comparison of overpressure distribution show that the blast wave model can give consistent results with numerical code.

2 REVISED PARAMETERS

According to π theorem, the mechanical quantities involved in air blast wave analysis are ambient pressure p_0, density ρ_0, sonic velocity a_0, total explosive energy E and distance R. Sonic velocity is written as $a_0 = \sqrt{k\, p_0/\rho_0}$ which are related to ambient pressure and density, and in which k is polytropic exponents of air. It is assumed that the total explosive energy is the only relevant parameter of explosive charge, which is applicable to the distance far larger than the characteristic size of the charge.

Sachs scaling for air blast wave is proportions theorem: The dimensionless scaled distance is written as $\overline{R} = R\Big/\sqrt[3]{E/p_0}$, and the scaled overpressure is $\Delta\overline{p} = \Delta p/p_0$, the scaled time is $\overline{t} = t a_0\Big/\sqrt[3]{E/p_0}$ and the scaled is $\overline{I} = I a_0\Big/\sqrt[3]{E p_0^{\,2}}$. After obtaining the pressure from the calculation model, the scaled density $\overline{\rho} = \rho/\rho_0$ and the scaled velocity $\overline{u} = u/a_0$ can be obtained according to the air shock wave relations between them.

WIT Transactions on The Built Environment, Vol 180,
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/SUSI180041

The relation between peak overpressure and explosion distance is usually analyzed in double logarithmic diagrams in literatures, on the bases of previous research [5] , eqn (1) is still used in this paper.

$$\lg \Delta p_s = \mathrm{a}\, \mathrm{e}^{-\mathrm{b}\bar{R}} - \mathrm{c} \lg \bar{R} + \mathrm{d}\,, \tag{1}$$

where a, b, c and d are parameters and those parameters are revised for the dimensionless normalized mechanical quantities based on data of numerical simulations as in eqn (2).

$$\lg \Delta \bar{p} = \begin{cases} 1.137\,\mathrm{e}^{-2.3776\bar{R}} - 1.3221 \lg \bar{R} - 0.39, & \bar{R} \geq 0.1 \\ -1.1443\,\mathrm{e}^{-16.545\bar{R}} - 2.2072 \lg \bar{R} - 0.1491, & \bar{R} < 0.1. \end{cases} \tag{2}$$

Comparison of the peak pressure between results computed by eqn (2) and numerical simulation are given in Fig. 1. Some test data of the peak overpressure from literatures at the large scaled distance are added in Fig. 2. Fig. 1 and Fig. 2 show that the results of the peak overpressure between numerical simulation and the fitted model agree very well.

After fitted data, the maximum negative overpressure $\Delta \bar{p}_f$ and the scaled positive phase impulse are described in a similar way as eqn (3) and eqn (4).

$$\lg \Delta \bar{p}_f = -1.9522\,\mathrm{e}^{-9.0387\bar{R}} - 1.0864 \lg \bar{R} - 0.8849\,, \tag{3}$$

$$\lg \bar{I}^+ = -0.2401\,\mathrm{e}^{-2.3552\bar{R}} - 1.0047 \lg \bar{R} - 1.3645\,. \tag{4}$$

The fitting results are in good agreement with the numerical simulation results as shown in Fig. 3 and Fig. 4 respectively.

The model of the scaled typical time $\bar{T}_r$, $\bar{T}_d$ and $\bar{T}_f$, which refer to the arrival time of shock wave, the duration time of positive overpressure and the arrival time of the maximum negative overpressure, need to be determined for describing overpressure distribution with time. $\bar{T}_r$ is also computed by the shock front speed as in previous literature [4]. $\bar{T}_d$ and $\bar{T}_f$ are computed as eqn (5) and eqn (6).

$$\bar{T}_d = \left(1 + k_d / \bar{R}\right) \bar{T}_r\,, \tag{5}$$

$$\bar{T}_f = \left(1 + k_f / \bar{R}\right) \bar{T}_r\,, \tag{6}$$

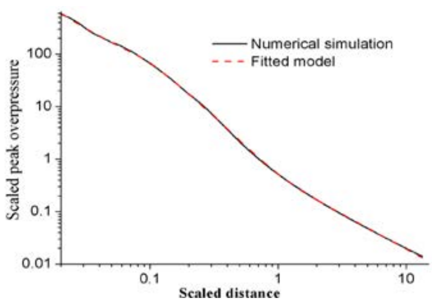

Figure 1: Comparison of the scaled peak overpressure with numerical simulation.

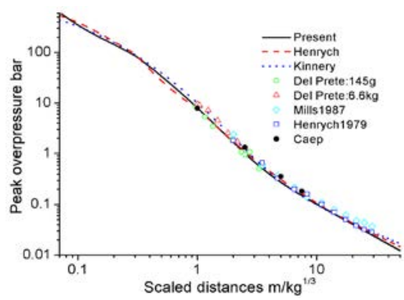

Figure 2: Comparison of the peak overpressure with data in literatures [2], [3], [5].

WIT Transactions on The Built Environment, Vol 180, © 2018 WIT Press
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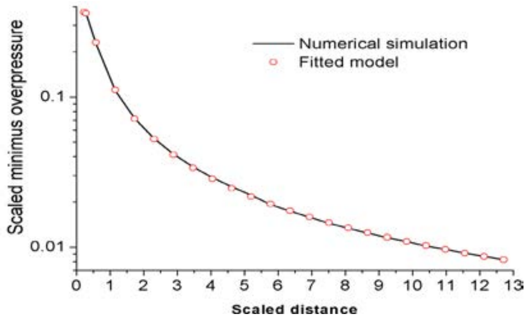


Figure 3: Comparison of the maximum negative overpressure.

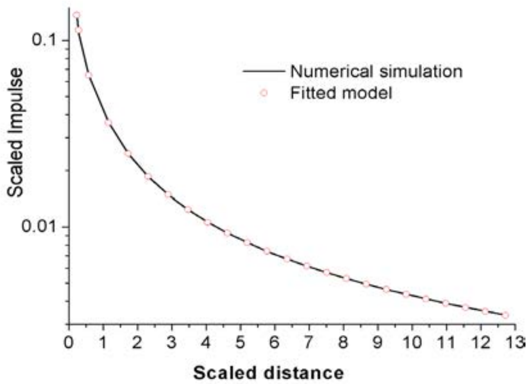


Figure 4: Comparison of the positive phase impulse.

where k_d and k_f are parameters. By fitted data of numerical simulation, k_f is determined as $k_f = 0.8957555$, and k_d will be determined by eqn (7). Fig. 5 shows good consistent results between fitted model and numerical simulation

$$k_f / k_d - 1 = 0.93 + 0.89\exp\left(-0.969\bar{R}\right). \tag{7}$$

Another important parameter of air blast wave is attenuation coefficient. There is no new change under high altitude condition. The calculation method and parameters are determined as in previous literature [4].

Fig. 6(a) and (b) show changing of ambient pressure, density and sonic velocity with height of altitude.

With introduction of these parameters and a simple code of computing all equations, the blast wave model can be applied to high altitude (low pressure and low density) explosion cases. some results of the model are given by graphs comparing to the results numerical simulations. The distribution of the explosive field pressure, density and velocity of explosive 80 kg TNT explosive at 5 km and 10 km is compared. The calculation results obtained by the engineering calculation model are in good agreement with the numerical simulation, as shown in Fig. 7.

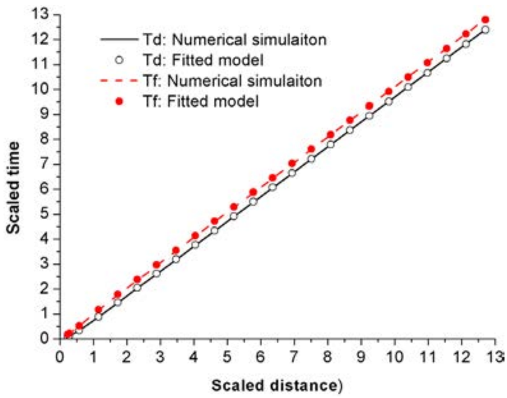


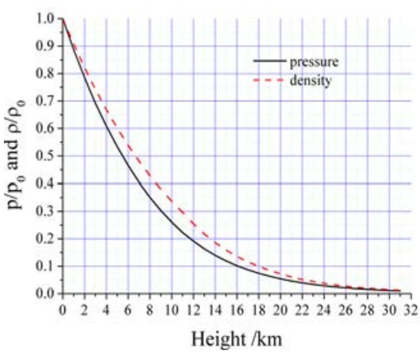
Figure 5: Comparison of the scaled time.

3 RESULTS OF THE PRESENT MODEL

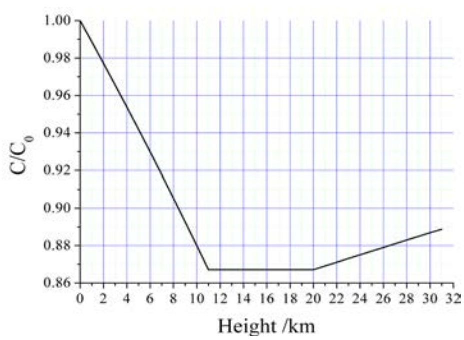
In addition, the distribution diagram of the non-dimensional peak overpressure of the explosive wave and the impulse of the positive pressure zone with the distance of the explosion is given for the problem of 1 kg TNT explosive at different height (above 30 km altitude), as shown in Fig. 8. It is clear that the explosion distance corresponding to the same non dimensional explosion peak overpressure and impulse increases with the increase of the explosion height, for example, the peak overpressure at 10 meters near the ground explosion is 0.1, and the corresponding explosion distance is about 26 meters at the altitude of 20 km altitude. The results of Fig. 8 can be used as a quick reference for experimental design and impact analysis of high altitude explosion.

4 CONCLUSION

Based on Sachs scaling, the engineering computational model on air blast wave at high altitudes is rebuilt and all the parameters can be determined according to results of numerical simulations. Comparison of pressure, density and velocity configuration for the different altitudes shows that the present engineering model can give consistent results with the numerical code. The scaled peak overpressure and the scaled impulse figure for the different altitudes are given for convenience of engineering application.

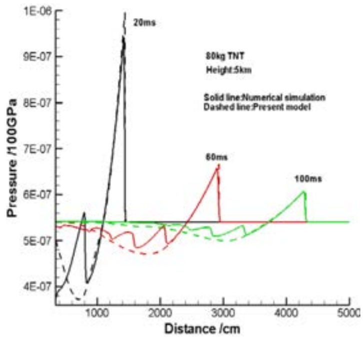


(a) Pressure and density.

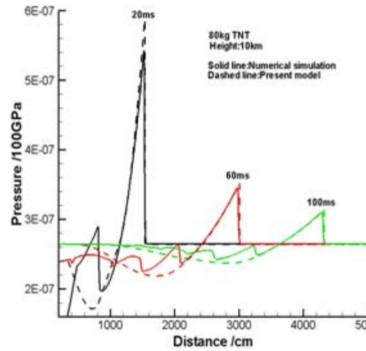


(b) Sonic velocity.

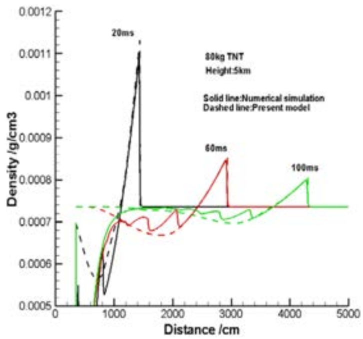
Figure 6: Ambient condition changing with height of altitude.



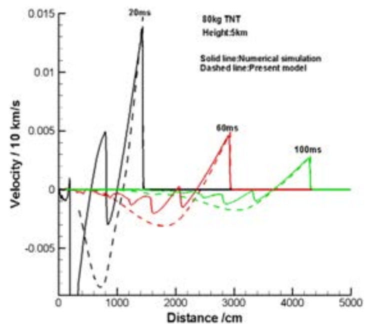
(a) Pressure at altitude of 5 km.



(b) Pressure at altitude of 10 km.

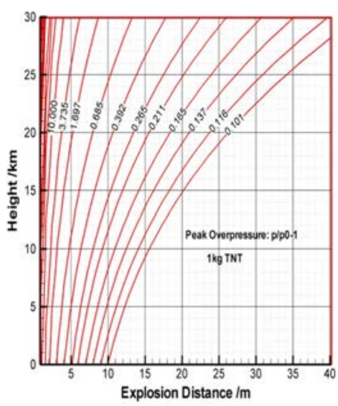


(c) Density at altitude of 5 km.

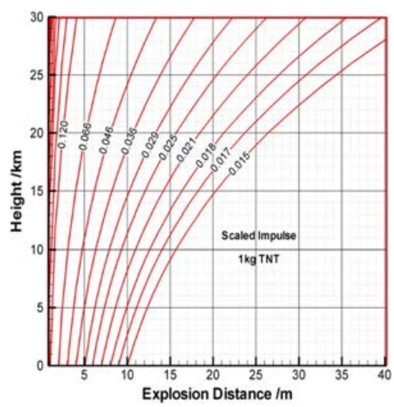


(d) Velocity at altitude of 5 km.

Figure 7: Comparison results between the model and numerical simulation.



(a) Peak overpressure.



(b) Impulse of the positive pressure.

Figure 8: Distribution of the scaled peak overpressure and impulse (1 kg TNT).

ACKNOWLEDGEMENTS

The work was performed under the auspices of the National Defense Basic Scientific Research Program (B1520132012) and the National Natural Science Foundation of China Youth Fund (11702028).

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