Air Blast Validation Using ANSYS/AUTODYN

Neetu Jha, B. S. Kiran Kumar

Technology Specialist, ANSYS India, Regional Technical Manager, ANSYS India

Abstract

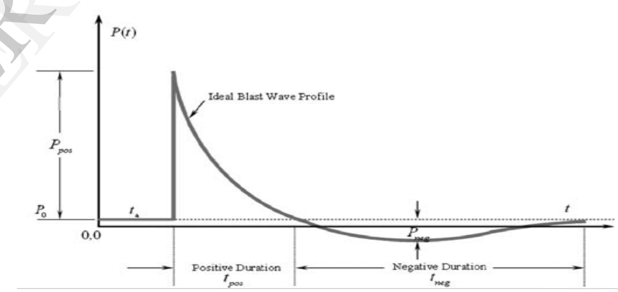
ANSYS/AUTODYN capabilities are benchmarked here for studying the blast response in Air. The blast pressure developed due to explosion of TNT in air obtained from AUTODYN program is validated with #1 analytical results and # 2 CONWEP program (commercial code). Validation of blast pressure is very important because the pressure developed during blast response event is one of the critical parameter used for design verification and validation in structure design. The cost of simulation software is economical when compared to experimental testing and hence more number of iterations can be conducted in software. Since the blast response is a highly non-linear phenomenon to capture the blast response accurately we have used AUTODYN program based on explicit time integration scheme. In this paper two cases are presented; first case compares the pressure obtained from analytical equation with AUTODYN results. Second case compares the pressure obtained from commercial code (CONWEP) with AUTODYN result. The simulation is done using 1D analysis of AUTODYN with Multi-Material Euler solver. Air and TNT materials are used which are directly available in AUTODYN material library. A detonator is placed at the center of explosive to start the blast. Different mesh sizes are used for results validations in both the cases. AUTODYN results matches very well with analytical results and CONWEP program.

1. Introduction

An explosion in air releases energy rapidly which generates a pressure wave of finite amplitude. Hot gases produce pressure of 100-300 Kbar and temperature of about 3000-4000^0 C. These hot gases expand at an initial velocity which varies from 1800 to 9100 m/s, which results into movement of ambient atmosphere. Because of this, a layer of compressed air is formed in front of hot gases. This layer is called blast wave. Blast wave has important parameters such as maximum overpressure, duration and impulse [5; 6]. These parameters are very important to know as it has great impact on structure design.

As blast wave moves away from the detonation point its pressure drops significantly and becomes equal to the atmospheric pressure. The Blast wave loses its initial heat and initial velocity at a distance 40 to 50 times the diameter of the charge from the detonation point [5]. Changes in the pressure of a point at a certain distance from the explosive with respect to time are shown in Figure 1.

The generated blast wave contains two phases; a positive one, which is called pressure, and a negative one, which is called suction [7]. The absolute difference between the produced pressure and the pressure of the environment is called overpressure and is greater and more important than the suction phase. Therefore, only the positive phase is considered in the loading of the structures [5; 6; 7].



"**Figure 1.** Blast pressure time profile"

It can be seen in Figure 1 that the overpressure will decay after it reaches its maximum. The rate of the decay of the overpressure with respect to time can be approximated with an exponential function called a Friedlander curve. See Eq. 1 [8]:

$$P(t) = P_0 + P_{pos}\left(1 - \frac{t}{t_{pos}}\right)e^{\frac{-bt}{t_{top}}} \tag{1}$$

Where P is the overpressure in time t, Ppos is the maximum overpressure, tpos is the positive phase duration, and b is a coefficient that shows the decay of the curve.

There are several analytical equations developed by many scientists to measure the blast parameters. Brode, is the first scientist who developed an analytical equation for shockwave calculation and presented a semi-analytical equation for maximum overpressure [7]. Further this equation was modified by other researchers [7].

Kinney and Graham [11] also presented following equations for estimating the maximum overpressure, duration, and impulse. See Eq. 2

$$P_{pos} = P_0 \frac{808\left[1+\left(\frac{Z}{4.5}\right)^2\right]}{\sqrt{1+\left(\frac{Z}{.048}\right)^2}} \times \frac{1}{\sqrt{1+\left(\frac{Z}{0.32}\right)^2}} \times \frac{1}{\sqrt{1+\left(\frac{Z}{1.35}\right)^2}} (bar)$$

$$t_{pos} = W^{1/3} \frac{980\left[1+\left(\frac{Z}{0.54}\right)^{10}\right]}{\left[1+\left(\frac{Z}{0.02}\right)^3\right]} \times \frac{1}{\left[1+\left(\frac{Z}{0.74}\right)^6\right]} \times \frac{1}{\left[1+\left(\frac{Z}{6.9}\right)^2\right]} (mili\sec ond)$$

$$I_{pos} = \frac{0.067\sqrt{1+\left(\frac{Z}{0.23}\right)^4}}{Z^2\sqrt[3]{1+\left(\frac{Z}{0.23}\right)^3}} (bar-ms) \qquad (2)$$

All equations use scaled distance (Z) for calculating the parameters. See Eq. 3:

$$Z = \frac{R}{W^{1/3}} \qquad (3)$$

Where R represents the distance from the detonation point in meters and W is the mass of TNT charge in kilograms.

In order to calculate blast wave parameters versus scaled distance, in structural design applications, some graphs are presented to be employed [9;10]. These graphs, which are presented in the report of the weapons effects calculation program CONWEP, are the results of numerous field experiments. Therefore, they can be used instead of experimental results for designing resistance to blast wave.

In this paper, Blast wave parameter (over pressure) at a given distance from the center of explosion, is calculated by numerical simulation code AUTODYN and have been compared with Kinney Graham analytical equation result and CONWEP result.

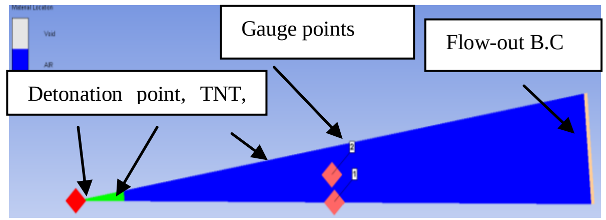
2. Numerical simulation

Two cases have been solved in AUTODYN for air blast pressure validation.

Case1: 10 kg of TNT is detonated in air and pressure generated at a distance of 3m from the center of blast charge is compared with the pressure obtained from analytical equation.

Case2: 100 lb of TNT is detonated in air and pressure generated at a distance of 1m from the center of blast charge is compared with CONWEP result and analytical equation.

The blast in air can be modelled using one-dimensional approach. In AUTODYN one-dimensional simulation is modeled using 2D-axisymmetric solver in the shape of a wedge. The angle of the wedge is defined by AUTODYN. Only wedge inner radius and outer radius needs to be defined. A schematic diagram of the wedge is shown in Figure 2.



"Figure 2. One dimensional wedge model in AUTODYN"

The dimension of the wedge depends upon charge weight and location of pressure measurement. However radius of the charge can be defined based on below formula.

Volume of TNT= mass of TNT/density of TNT

Density of TNT = 1.63 gm /cm^3

Volume of TNT = 4/3 * π *(R^3- r^3)

Here, r = 10.0 mm (minimum wedge radius)

In case-1, size of wedge is 5000mm and radius of charge is 114mm. However in case-2, size of wedge is 2000mm and radius of charge is 188mm.

2.1. Material Properties

Air and TNT material properties are selected from AUTODYN material library. Air has following ideal gas EOS [4]. See Eq.4.

$$P = (\gamma - 1)\rho e + P_{shift} \qquad (4)$$

In this equation, γ is the adiabatic exponent, ρ represents air density, e is internal air energy, and Pshift represents original gas pressure.

TNT has JWL EOS. The JWL equation of state is the most appropriate equation used for modelling explosives. In addition, it can be applied to calculate the pressure reduction of up to 1 Kbar. The JWL equation of state is as follows [4]. See Eq.5.

$$P = A\left(1-\frac{w}{R_1V}\right)e^{-R_1V} + B\left(1-\frac{w}{R_2V}\right)e^{-R_2V} + \frac{wE}{V} \qquad (5)$$

The properties of both the materials are given below.

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"**Table 1.** Material properties of Air"

Variable	Value
Density (kg/m3)	1.225
Gamma	1.40
Specific heat (KJ/gK)	0.000718
Reference Temperature (K)	288

"**Table 2**. Material properties of TNT"

Variable	Value
Reference Density (kg/m3)	1630
C1	374,00
C2	3750
R1	4.15
R2	0.09
w	0.35
C-J Detonation Velocity (m/ms)	6.93
C-J Energy/unit volume (MJ/m3)	6000
C-J Pressure (MPa)	21,000

2.2. Boundary Condition

A Flow-out boundary condition is defined at the end of wedge. This boundary condition will allow pressure wave to go out of the domain without reflecting any pressure back to the domain [4].

2.3. Gauge Points

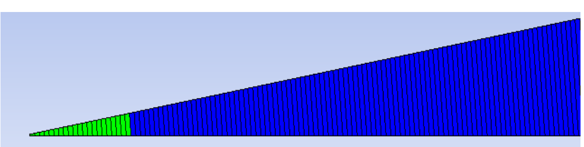
Gauge points are located at 3m and 1m from the center of blast in case-1 and case-2 respectively to measure the pressure at these points.

2.4. Detonation

A detonation point is located at the center of explosive (0, 0, 0) to start the explosion at time zero.

2.5. Mesh

One degree quadrilateral element has been used to model the wedge. Since accuracy of the results is highly dependent on mesh therefore different sizes of mesh have been used in case-1 and case-2.
In case-1; 5mm, 2.5mm and 1mm mesh size have been considered. However in case-2; 5mm, 2.5mm, 1mm and 0.25mm mesh sizes have been considered.



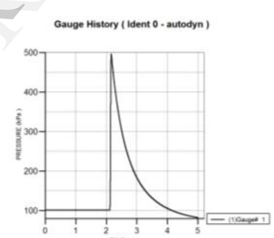
"**Figure 4.** Mesh of AUTODYN 1D model"

3. Results and Discussion

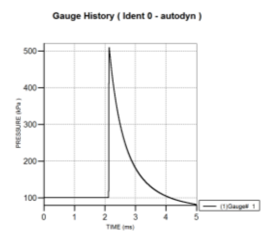
Case-1**:** Table -3, shows the blast pressure, due to blast of 10kg of TNT at 3m from the center of explosion. AUTODYN spherical symmetric analysis results are compared with analytical equation given by Kinney-Graham. Different element sizes are used in AUTODYN model to study the mesh convergence.
Figure-5 shows the overpressure-time histories for three element sizes used in AUTODYN model.
This result shows that as mesh is refined, overpressure value come closure to Kinney-Graham analytical equation result. With most refined mesh i.e. element size 1mm difference in AUTODYN result and analytical result is 0.19%.

"**Table 3.** Overpressure in AUTODYN and Kinney-Graham"

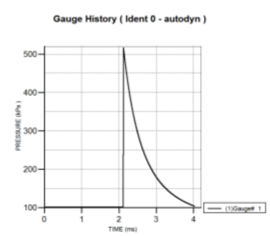
Case-1	Maximum Over pressure (KPa)
AUTODYN-2D (Element size 5mm)	500
AUTODYN-2D (Element size 2.5mm)	507
AUTODYN-2D (Element size 1mm)	512
Kinney-Graham	511



Element size = 5mm



Element size = 2.5mm



Element size = 1mm

"**Figure 5.** Overpressure vs. Time graph for different element sizes"

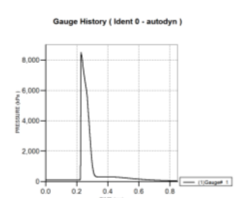
Case-2: The above analysis is repeated for 100lb. of TNT and the results are compared with analytical equation given by Kinney-Graham and CONWEP.
Table -4, shows the blast pressure, due to blast of 100lb of TNT at 1m from the center of explosion. AUTODYN spherical symmetric analysis results are

compared with that of analytical equation given by Kinney-Graham and CONWEP results.
These results show that as mesh is refined, overpressure value comes close to analytical results. With most refined mesh and element size 0.25mm difference in AUTODYN result, analytical formula given by Kinney-Graham and CONWEP result is 4%.

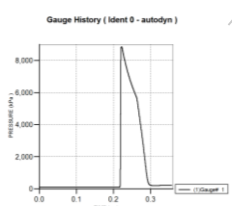
"Table 4. Overpressure in AUTODYN, Kinney-Graham and CONWEP"

Case-2	Maximum Over pressure (KPa)
AUTODYN-2D (Element size 5mm)	8.5e3
AUTODYN-2D (Element size 2.5mm)	8.84e3
AUTODYN-2D (Element size 1mm)	9.2e3
AUTODYN-2D (Element size 0.25mm)	9.6e3
Kinney-Graham	10e3
CONWEP	10e3

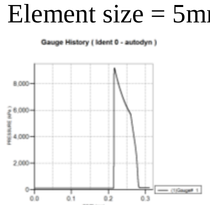
Figure-6 shows the overpressure-time histories for different mesh sizes of AUTODYN model.
Figure-7 shows the overpressure-time history graph for most refined mesh of AUTODYN model and CONWEP result.



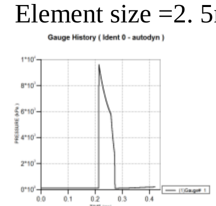
Element size = 5mm



Element size =2. 5mm

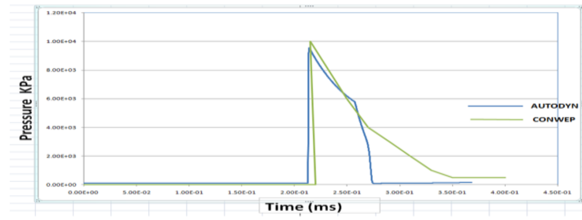


Element size = 1mm



Element size = 0.25mm

"Figure 6. **Overpressure vs. Time graph for different element sizes"**



"Figure 7. AUTODYN and CONWEP Pressure vs. Time graph"

4. Conclusion

In this paper, the explosion phenomenon and blast wave propagation in air are successfully simulated and the blast wave parameter (over pressure) is calculated using ANSYS/AUTODYN program. Maximum overpressure which is calculated by ANSYS/AUTODYN is compared with the analytical equation presented by Kinney-Graham and CONWEP result. Simulation studies show that AUTODYN results match very well with analytical equation. However, the accuracy of simulation is dependent on mesh size. With refined mesh studies the pressure results obtained is closure to analytical results as tabulated in Table 4.

5. References

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