Blast Detonated by Impact Simulation

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Abstract

The purpose of this study is to present parameters required for blast detonated by impact simulation in LS-DYNA with comprehensive approach and compare with AUTODYN results. Blast detonated by impact is a widely used method for controlled blast. However, design of the problem is more likely limited to simulation results. For a proper and reliable simulation, it has to be taken care of reacted and unreacted state parameters of detonative product, mesh size and method.

*LS-DYNA explicit code uses keyword *EOS_IGNITION_AND_GROWTH_OF_REACTION_IN_HE for defining those parameters of the equation of state which brought by Lee and Tarver in 1980. EOS has two main parts reacted state and unreacted state. AUTODYN explicit code also uses almost the same parameters as defined in EOS LEE TARVER. Both of the codes uses same formulation based on Lee and Tarver's study which based on the assumption, supported by considerable experimental data, that ignition starts at hot spots and grows outwards from these sites. *MAT_ELASTIC_PLASTIC_HYDRO material model is used for defining material parameters in LS-DYNA.*

In general, these kind of simulations consist of HE based materials with a cover shell and a projectile which creates the impact. The projectile material, velocity, and size define the amount of impact energy. The cover shell material thickness and position can be defined like a target in ballistic simulations. After the cover shell is penetrated, the remaining of the projectile and velocity hits the HE material with the energy remained to the projectile can cause detonation or no detonation. In this aspects of design, everything becomes an important parameter for proper detonation. First part can be seen as penetration or ballistic, and the second part can be detonation or penetration. This makes the problem more complex.

*In this study, various HE materials and various geometrical designs are compared. In AUTODYN's material database, different materials can be reached. The same parameters have been also used in LS-DYNA and developed several designs as 2D and 3D. We like to present a work of COMP-B HE material and two different geometries with two different projectiles. Cover shells are defined as Steel SEA 1006 with JC material parameters and *EOS_Gruneisen and the projectile choose as Lead with *MAT_ELASTIC_PLASTIC_HYDRO with *EOS_Gruneisen.*

Beside geometries, another important parameter is meshing method for this kind of problems. Both conventional method, and volume fraction method have been discussed and result comparisons has been provided. For comparison, it has been tried to show 2D axial approach in many cases for the sake of simulation times but we also compared 2D to 3D, and we present how hard to model a non-axial case can be modelled. There is one more option for mesh method or approach method which is ALE vs Lagrangian mesh methods. Although the most of the work done in ALE approach we also made some comparisons with Lagrange mesh approach.

Also presenting this kind of simulation results requires precautious handling we like to present proper comparison post methods for results for both codes.

Finally we put considerable amount of data from those simulations. We like to point out the parameters and result differences for ignition and growth equation of state for different codes and mesh parameters from an academic and industrial perspectives.

KEYWORDS:
"*EOS_IGNITION_AND_GROWTH_OF_REACTION_IN_HE","*MAT_ELASTIC_PLASTIC_HYDRO", "*EOS_Gruneisen

1 Introduction

E.L. Lee ad CM. Tarver discussed ignition and growth model of explosive initiation in detail in 1980 [Lee &Tarver, 1980]. Ignition and growth EOS is defined for explaining blast detonation caused by impact. As this can be examined and defined controlled blast can be arranged with purpose. Designing a detonation is a very complex simulation which depends on various parameters based on explosive modelling equations with unreacted and reacted states, also you need to define proper penetration for housing and projectile. The simulation has three parts penetration of projectile, unreacted and reacted state of HE material. Their work based on the assumptions based on various experimental data. That ignition starts with hot spots and grows as detonation if there is enough energy occurred. Lee and Tarver described EOS with two major parts reacted state and unreacted state.

As LS-DYNA Manual Volume II R10.0 describes;

Equation of State Form 7 (*EOS_IGNITION_AND_GROWTH_OF_REACTION_IN_HE) *is used to calculate the shock initiation (or failure to initiate) and detonation wave propagation of solid high explosives. It should be used instead of the ideal HE burn options whenever there is a question whether the HE will react, there is a finite time required for a shock wave to build up to detonation, and/or there is a finite thickness of the chemical reaction zone in a detonation wave. At relatively low initial pressures (<2-3 GPa), this equation of state should be used with material type 10 for accurate calculations of the unreacted HE behavior. At higher initial pressures, material type 9 can be used. A JWL equation of state defines the pressure in the* <u>*unreacted*</u> *explosive as*

$$P_e = r_1 e^{-r_5 V_e} + r_2 e^{-r_6 V_e} + r_3 \frac{T_e}{V_e}, \qquad \left(r_3 = \omega_e C_{v_r}\right) \quad (1)$$

where Ve and Te are the relative volume and temperature, respectively, of the unreacted explosive. Another JWL equation of state defines the pressure in the <u>*reaction products*</u> *as*

$$P_p = a e^{-xp_1 V_p} + b e^{-xp_2 V_p} + \frac{g T_p}{V_p}, \qquad \left(g = \omega_p C_{v_p}\right) \quad (2)$$

where Vp and Tp are the relative volume and temperature, respectively, of the reaction products. As the chemical reaction converts unreacted explosive to reaction products, these JWL equations of state are used to calculate the mixture of unreacted explosive and reaction products defined by the fraction reacted F(F = O implies no reaction, F = 1 implies complete reaction). The temperatures and pressures are assumed to be equal ($Te=T p, p e=p p$) and the relative volumes are additive, i.e.,

$$V = (1-F)V_e + FV_p \quad (3)$$

The chemical reaction rate for conversion of unreacted explosive to reaction products consists of three physically realistic terms: an ignition term in which a small amount of explosive reacts soon after the shock wave compresses it; a slow growth of reaction as this initial reaction spreads; and a rapid completion of reaction at high pressure and temperature. The form of the reaction rate equation is

$$\frac{\partial F}{\partial t} = \overbrace{\mathrm{FREQ} \times (1-F)^{\mathrm{FRER}} \left(V_e^{-1} - 1 - \mathrm{CCRIT}\right)^{\mathrm{EETAL}}}^{\text{Ignition}} + \overbrace{\mathrm{GROW1} \times (1-F)^{\mathrm{ES1}} F^{\mathrm{AR1}} p^{\mathrm{EM}}}^{\text{Growth}} \quad (4)$$
$$+ \underbrace{\mathrm{GROW2} \times (1-F)^{\mathrm{ES2}} F^{\mathrm{AR2}} p^{\mathrm{EN}}}_{\text{Completion}}$$

The ignition rate is set equal to zero when $F \geq$ FMXIG, the growth rate is set equal to zero when $F \geq$ FMXGR, and the completion rate is set equal to zero when $F \leq$ FMNGR .

Details of the computational methods and many examples of one and two dimensional shock initiation and detonation wave calculation can be found in the references (Cochran and Chan [1979], Lee and Tarver [1980]). Unfortunately, sufficient experimental data has been obtained for only two solid explosives to develop very reliable shock initiation models: PBX-9504 (and the related HMX-based explosives LX14,LX-10,LX-04, etc.) and LX-17 (the insensitive TATB-based explosive). Reactive flow models have been developed for other explosives (TNT, PETN, Composition B, propellants, etc.) but are based on very limited experimental data.

Some of the results compared with AUTODYN explicit software and when we checked the AUTODYN Explosive Initiation User's Manual Rev. 4.3 (Lee-Tarver Ignition & Growth) we found out that same formulations with a little difference parameterization embedded to the code.

2 Simulation definition and boundary conditions

Simulation consist of basically four different parts; first is projectile mainly Copper or Lead, second part is shell cover which is commonly steel, third part is HE material inside the shell cover and fourth part is surrounding environment which is air.

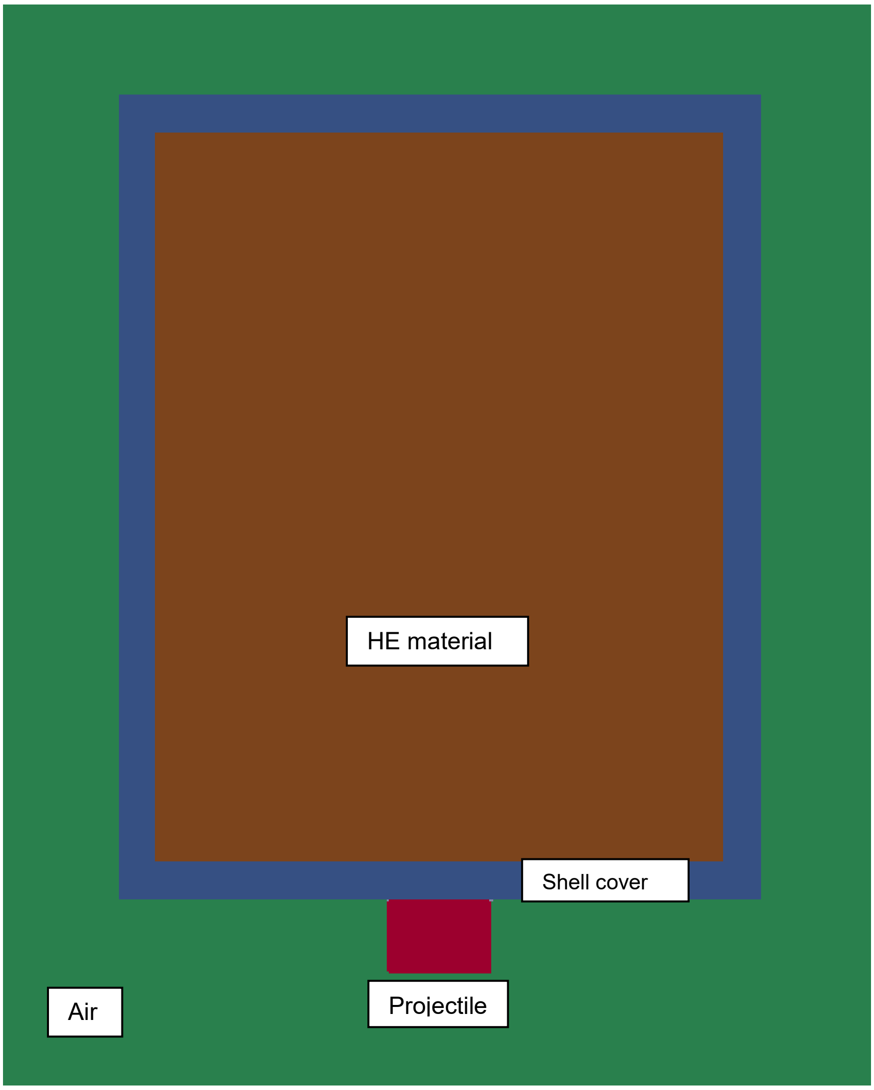

Fig.1: Simulation definition and parts

Projectile has been chosen as lead. Projectile dimension varies on size and velocity. Projectile has been modeled with two different dimensions as cylinder. These cylinders has same height with two different radiuses. Small one has a diameter of 0.32 cm and big one has 0.64 cm. Both have 0.32 cm height. Also for both projectiles two different velocities has been chosen. First velocity is 0.060 cm/us and the second velocity is 0.12 cm/us.

Normally in these kind of simulations the aim is to find a threshold velocity for the designed system. But as a numerical approach calculating threshold (go/no go) velocities can be vital for the system design but in our work we approached as a test situation set up and both velocities are practically can be used in defense industry.

Shell cover part has 0.6 cm thickness and also modelled as a cylinder. Cylinder height is 6 cm and diameter is 6 cm. Material is chosen as Steel SEA 1006.

He material is chosen as COMP-B which also commonly used in defense industry. And size has been fitted to shell cover. COMP-B’s weight is 150 g.

Environment modelled as air and represented as vacuum in the simulations. Vacuum zone defined enough to present the limits of the exploded shell cover’s behavior in 100us.

However the simulation termination time is 15us for presentational purposes. In all simulations the detonation occurs or not, termination time gave enough evidence to present the situation.

3 Material Characterization

3.1 HE Material Characterization

In this study Comp-B was chosen. Comp-B parameters can be found on different studies. Besides AUTODYN material library has wide range of opportunities for explosive materials for EOS Lee-Tarver (*EOS_IGNITION_AND_GROWTH). In AUTODYN's library COMPB-JJ3 was used in simulations (Tarver, 1997[1]). (Unit system is cm/gr/us/Mbar)

AUTODYN	AUTODYN	LS-DYNA	LS-DYNA
*EOS LEE-TARVER	Value	Value	*EOS_IGN_GROWTH
A=Reacted EOS JWL Parameter A (Mbar)	5.242	5.242	A=A
B=Reacted EOS JWL Parameter B (Mbar)	0.07678	0.07678	B=B
R1=Reacted EOS JWL Parameter R1 (none)	4.2	4.2	XP1=R1
R2=Reacted EOS JWL Parameter R2 (none)	1.1	1.1	XP2=R1
RRB=Growth reaction ratio exp. (none)	0.667	0.667	FRER=b
W=Reacted EOS JWL Parameter w (none)	0.34	3.40E-06	G=w_p*Cvp
AUR=Unreacted EOS JWL Parameter A (Mbar)	778.1	778	R1=A
BUR=Unreacted EOS JWL Parameter B (Mbar)	-0.05031	-0.05031	R2=B
WU=Unreacted EOS JWL Parameter w (none)	0.8938	2.22E-05	R3=w_e*Cvr
R1U=Unreacted EOS JWL Parameter R1 (none)	11.3	11.3	R5=R1
R2U=Unreacted EOS JWL Parameter R2 (none)	1.13	1.13	R6=R2
FIGMAX=Max. reac. Ratio: ignition (none)	0.022	0.022	FMXIG=Figmax
RRI=Ignition parameter I (1/us)	4.00E+06	4.00E+06	FREQ=I
RRG1=Growth parameter G1 (Mbar^-2/us)	850	850	GROW1=G1
RRY=Growth pressure exp. Y (none)	2	2	EM=y
RRD=Growth reaction ratio exp. D (none)	0.667	0.667	AR1=d
RRC=Growth reaction ratio exp. C (none)	0.222	0.222	ES1=c
		1.00E-05	CVP (Mbar K^{-1})
		2.49E-05	CVR (Mbar K^{-1})
RRX=Ignition compression exp. (none)	7	7	EETAL=x
RRA=Ignition critical compression (none)	0	0	CCRIT=a
EZIG=C-J Energy/unit volume (MBar)	0.085	0.085	ENQ=E0
		298	TMPO (K)=T0
RRG2=Growth parameter G2 (Mbar^-2/us)	660	660	GROW2=G2
RRG=Growth reaction ratio exp. G (none)	1	1	AR2=g
RRE=Growth reaction ratio exp. E (none)	0.333	0.333	ES2=e
RRZ=Growth reaction ratio exp. Z (none)	3	3	EN=z
FG1MAX=Min. reac. Ratio: growth G1 (none)	0.6	0.6	FMXGR= Fg1max
FG1MIN=Min. reac. Ratio: growth G2 (none)	0	0	FMNGR= Fg2max
DETV=C-J Detonation velocity (cm/us)	0.798		
PCJ=C-J Pressure (Mbar)	0.295		
WREAC=Reaction zone with (none)	2.5		
DFMAX=Max change in reaction ratio (none)	1		
VUMAX=Maximum rel. vol. in tension (none)	1.1		
VVNS=Unreacted Von Neumann spike rel. vol. (none)	0.6933		
EZIU=Unreacted C-J Energy / unit volume (Greg/mm3)	-0.00612		
Strength / Von Mises			*MAT_ELASTIC_PLASTIC_HYDRO
Density (g/cm3)	1.717	1.717	Ro
Shear modulus (Mbar)	0.035	0.035	G
Yield (Mbar)	0.002	0.002	SIGY

Table 1: Material characterization of COMP-B in AUTODYN and LS-DYNA

3.2 Steel 1006

As shell cover Steel SEA 1006 material has been chosen for simulation. For a better penetration definition for Steel SEA 1006 material defined as *MAT_015_JOHNSON_COOK with *EOS_GRUNEISEN.

Steel SEA 1006 *MAT_015_JOHNSON_COOK							
MID	RO	G	E	PR	DTF	VP	RATEOP
-	7.896	0.818	0	0.3	0	0	0
A	B	N	C	M	TM	TR	EPSO
0.0035	0.00275	0.36	0.022	1	1811	300	1
CP	PC	SPALL	IT	D1	D2	D3	D4
4.52E-06	0	2	0	0	0	0	0
D5	C2/P	EROD	EFMIN	NUMINT			
0	0	0	0	0			
Steel SEA 1006 *EOS_GRUNEISEN							
EOSID	C	S1	S2	S3	GAMAO	A	E0
-	0.4568	1.49	0	0	2.17	0	0
V0							
0							

Table 2: Material definition of Steel SEA 1006.

3.3 Lead

As projectile Lead material has been chosen. As a general approach Lead has been defined as *MAT_ELASTIC_PLASTIC_HYDRO with *EOS_GRUNEISEN.

LEAD *MAT_ELASTIC_PLASTIC_HYDRO							
MID	RO	G	SIGY	EH	PC	FS	CHARL
-	11.34	0.1113	3.00E-04	0	0	0	0
EPS1	EPS2						
0	0						
ES1	ES2						
0	0						
LEAD *EOS_GRUNEISEN							
EOSID	C	S1	S2	S3	GAMAO	A	E0
-	0.2092	1.452	0	0	2	0	0
v0							
0							

Table 3: Material definition of LEAD

3.4 Air

Air has been modelled as vacuum material. Air represents the void in simulation and has no effect in penetration and blast, but affects the enlargement and fragmentation of steel cover after the detonation. Also increases the model size so there need to be care taken for defining boundaries of void. In this simulation, domain modelled as 8 cm x 8 cm x 8 cm cube. *MAT_VACUUM has been used in simulations. Only input required for vacuum is density it is also taken 0. In axisymmetric and quarter symmetric cases the whole domain can be define as 4 cm x 4 cm x 8 cm.

4 Simulation approach and defining simulation parameters

4.1 2D Axisymmetric ALE model approach

In this study designed example created to be easily defined in 2D axisymmetric ALE simulation. For a proper ALE simulation you need to define ALE multi material groups, ALE 2D section card with ALEFORM 11 and ELFORM 14 for asymmetry and ALE Control Cards.

Initial volume fraction geometry card of LS-DYNA also supports 2D situations. In 2D you basically define the section of projectile with initial velocity, after first you define the steel cover as full and then you can define the COMP-B with dimensions. You also need to check the tail and head directions of the initially filled materials.

```
*INITIAL_VOLUME_FRACTION_GEOMETRY
$#  fmsid  fmidtyp   bammg  ntrace
        8        1       4       3
$# conttyp  fillopt   fammg     vx      vy      vz   radvel   unused
        4        0       2     0.0    0.08     0.0       0
$#     x1       y1      z1      x2      y2      z2      r1      r2
      0.0      3.0     0.4     3.0     0.4     4.5     0.0     4.5
$# conttyp  fillopt   fammg     vx      vy      vz   radvel   unused
        4        0       3     0.0     0.0     0.0       0
$#     x1       y1      z1      x2      y2      z2      r1      r2
      0.0      4.5     8.0     4.5     8.0    20.5     0.0    20.5
$# conttyp  fillopt   fammg     vx      vy      vz   radvel   unused
        4        0       1     0.0     0.0     0.0       0
$#     x1       y1      z1      x2      y2      z2      r1      r2
      0.0      5.2     7.3     5.2     7.3    19.8     0.0    19.8
```

Fig.2: Initial volume fraction geometry card definition

Besides general control cards you need to define *DATABASE_EXTENT_BINARY with NEIPS for extra history variables which is vital for Burn fraction ratio (history variable #8) post also there is hint for this, always make your HE material the first part. Because LS-DYNA orders the history post according to part numbers and you can mix history variable #8 of JC material. Last post item is *DATABASE_TRACER and *DATABASE_TRHIST cards. LS-DYNA Tracers are fixed sensors to plot pressure or similar value in ALE domain. AUTODYN has similar post definition called gauges. Also AUTODYN models works like S-ALE and volume fraction (fill) for ALE simulations. To compare and see the pressure change in fixed space like 5 cm top of the bottom point in several simulations the best solution is tracer.

4.1.1 Mesh sizing

Mesh sizing is a critical issue for this short and fast detonative based and penetration based simulation. For 2D axial symmetric simulation model (domain) meshed with fixed sizing. Different mesh sizes compared for a proper run time and definition. Domain is 4 cm x 8 cm plate and for fixed sizing there have been modelled with 0,1cm, 0,05cm, 0.025cm and 0,0125cm square quad elements.

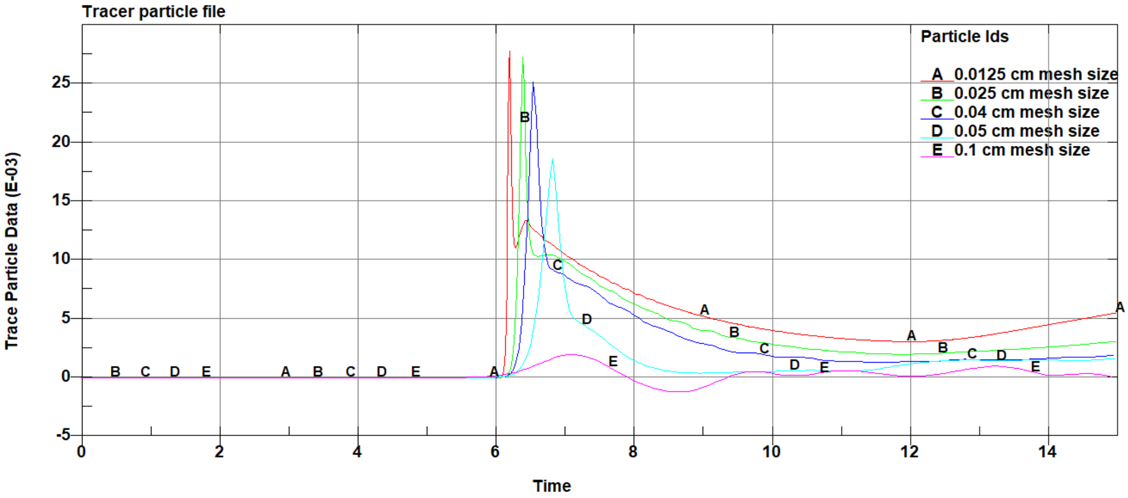

Fig.3: Mesh size comparison on pressure of low velocity and small projectile model (no detonation)

Mesh size	Pressure max. (MBar)	% Change ratio with previous result
0.1 cm	0.00197	%849.2
0.05 cm	0.0187	%34.2
0.04 cm	0.0251	%8.7
0.025 cm	0.0273	%1.8
0.0125 cm	0.0278	--

Table 4: Mesh size - pressure change ratio chart

As it can be seen from Table 4 mesh size is very critical for simulation accuracy. Also it affects the computational time that's why models have been decided to be modelled with **0.04 cm** fixed mesh size for accurate results to be comparable with 3D models. Grid size becomes 195625 Elements in 2D and for 3D.

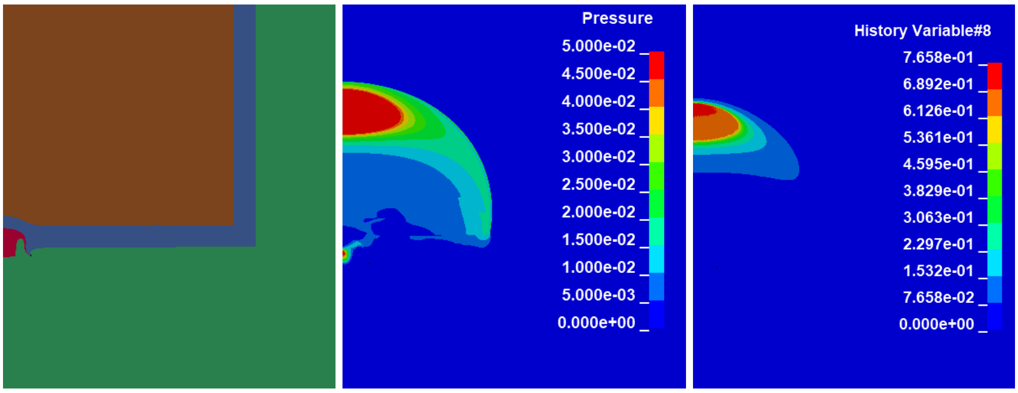

Fig.4: ALE Mat plot, pressure plot (very low according to detonation), burn fraction plot (should be 1 if detonation occurs, shows hot spots)

4.1.2 AUTODYN vs LS-DYNA

The study case has been also modelled in AUTODYN with 0.04cm mesh size with same parameters.

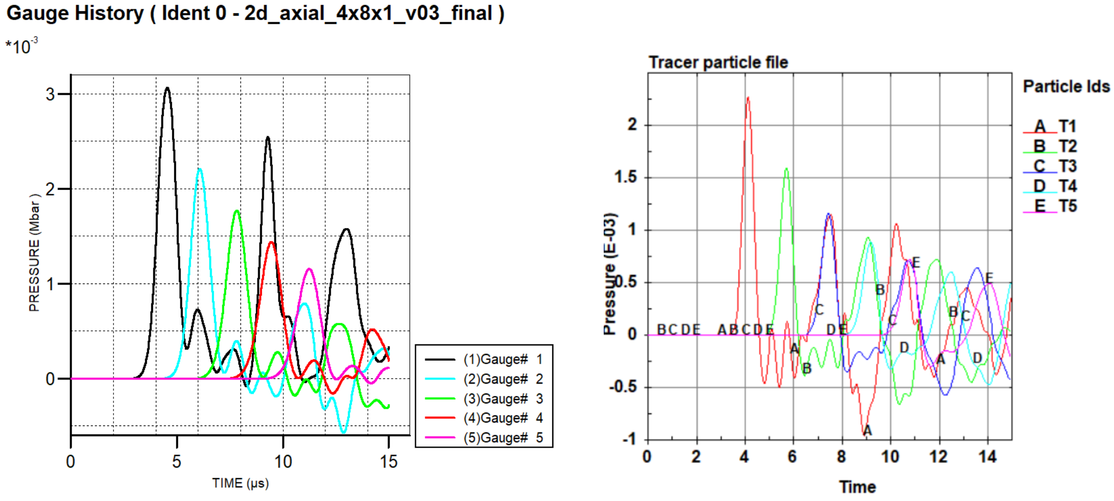

Fig.5: AUTODYN gauge points vs LS-DYNA tracker points results.

As it can be seen from the gauge and tracker points, results are different from each other with the same parameters.

4.2 3D quarter axisymmetric like ALE model approach

As the model can be defined as axisymmetric it can be modelled as 3D quarter with boundary conditions. In this part it has been modelled as this.

4.2.1 3D quarter axisymmetric like ALE model approach results

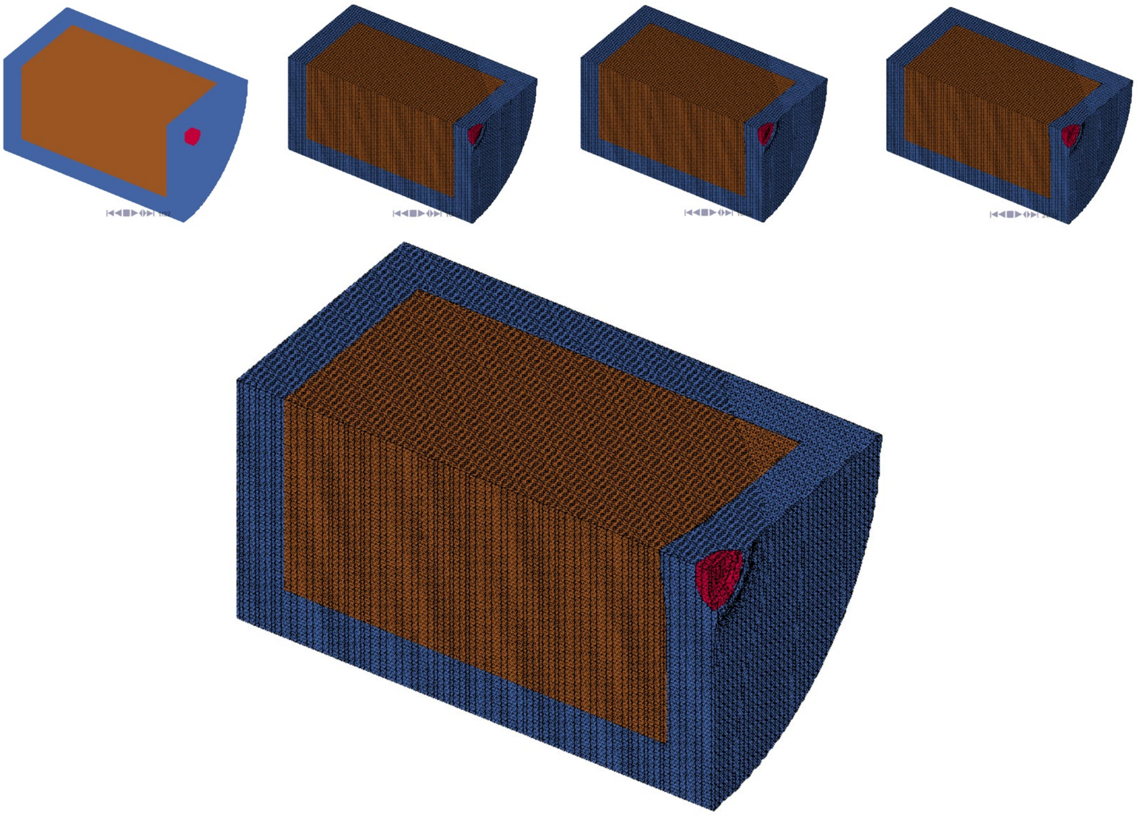

Fig.6: 3D quartes axisymmetric like ALE model approach results

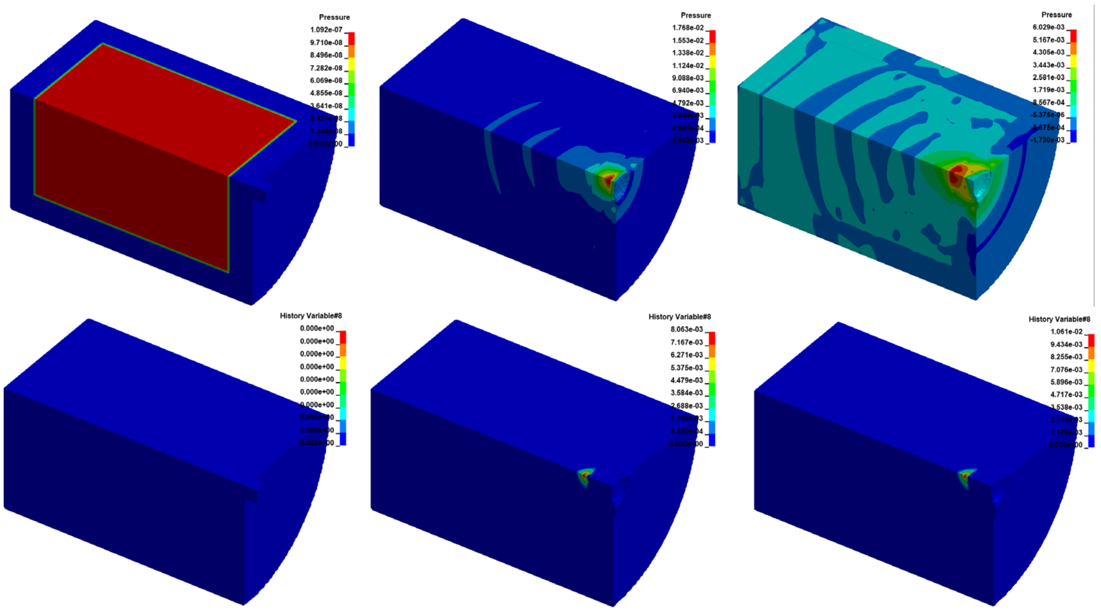

Fig.7: Pressure plot and Burn fracture plot of 3D quartes axisymmetric like ALE model

4.2.2 2D vs. 3D quarter axisymmetric like ALE model approach results

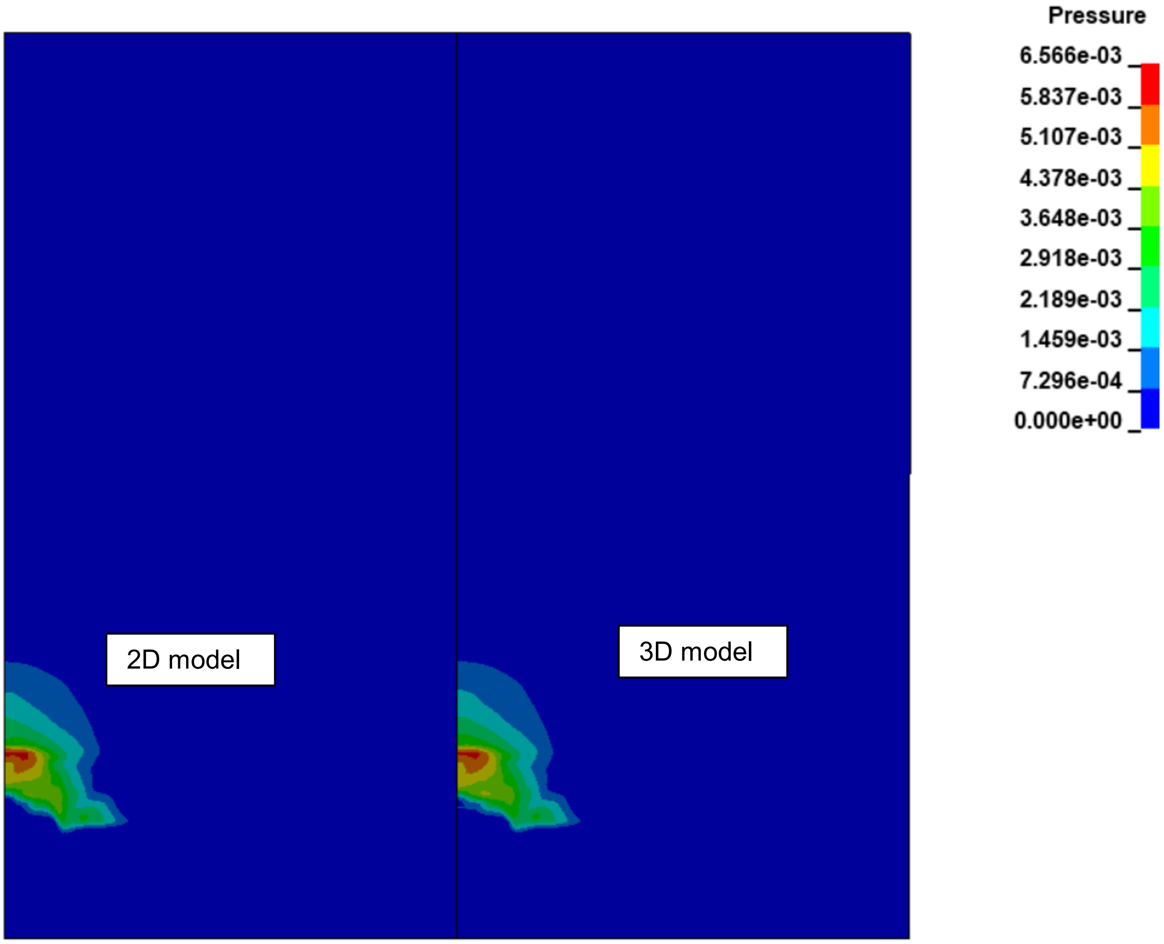

Fig.8: 2D vs 3D ALE model comparison of LS-DYNA

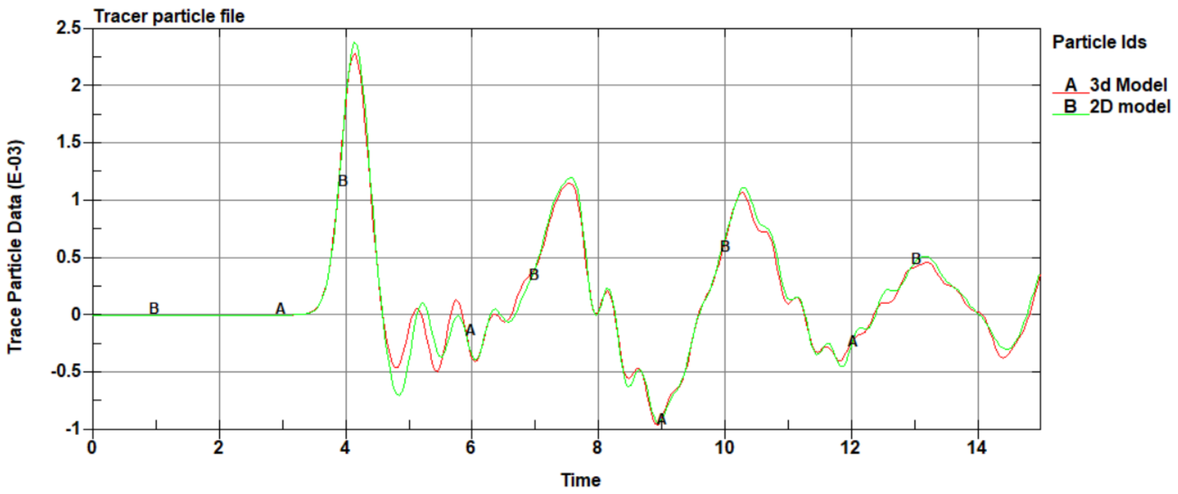

Fig.9: 2D vs 3D ALE model comparison of LS-DYNA

2D and 3D simulation results are very similar with fixed mesh size 0.04 cm.

4.2.3 LS-DYNA vs AUYODYN result comparison for 3D quarter axisymmetric like ALE model approach results

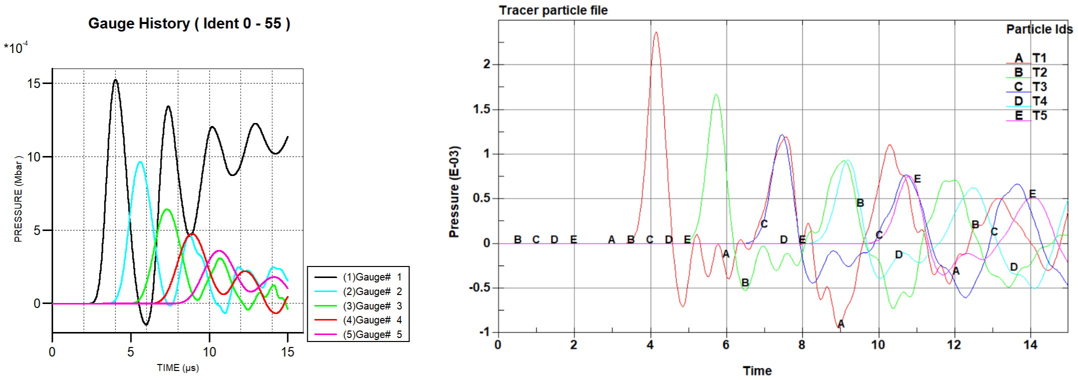

Fig.10: Result comparison

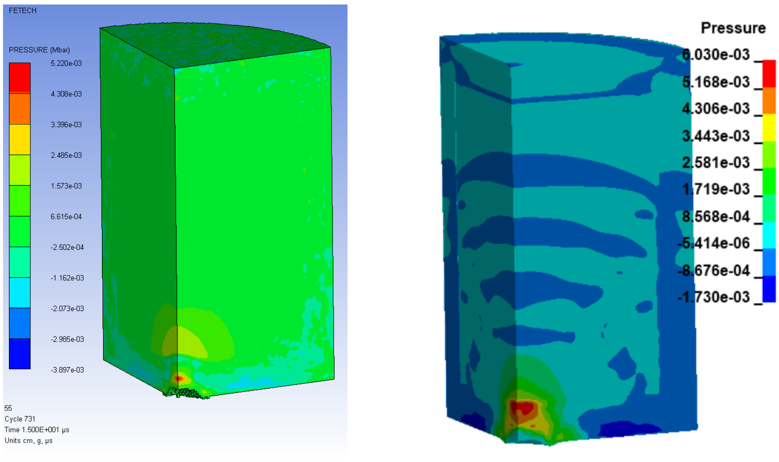

Fig.11: Result comparison

4.3 3D Quarter symmetric ALE model approach

In this model side impact has been investigated. Model has been created as 3D quarter symmetric. Figure 12 show the case set up.

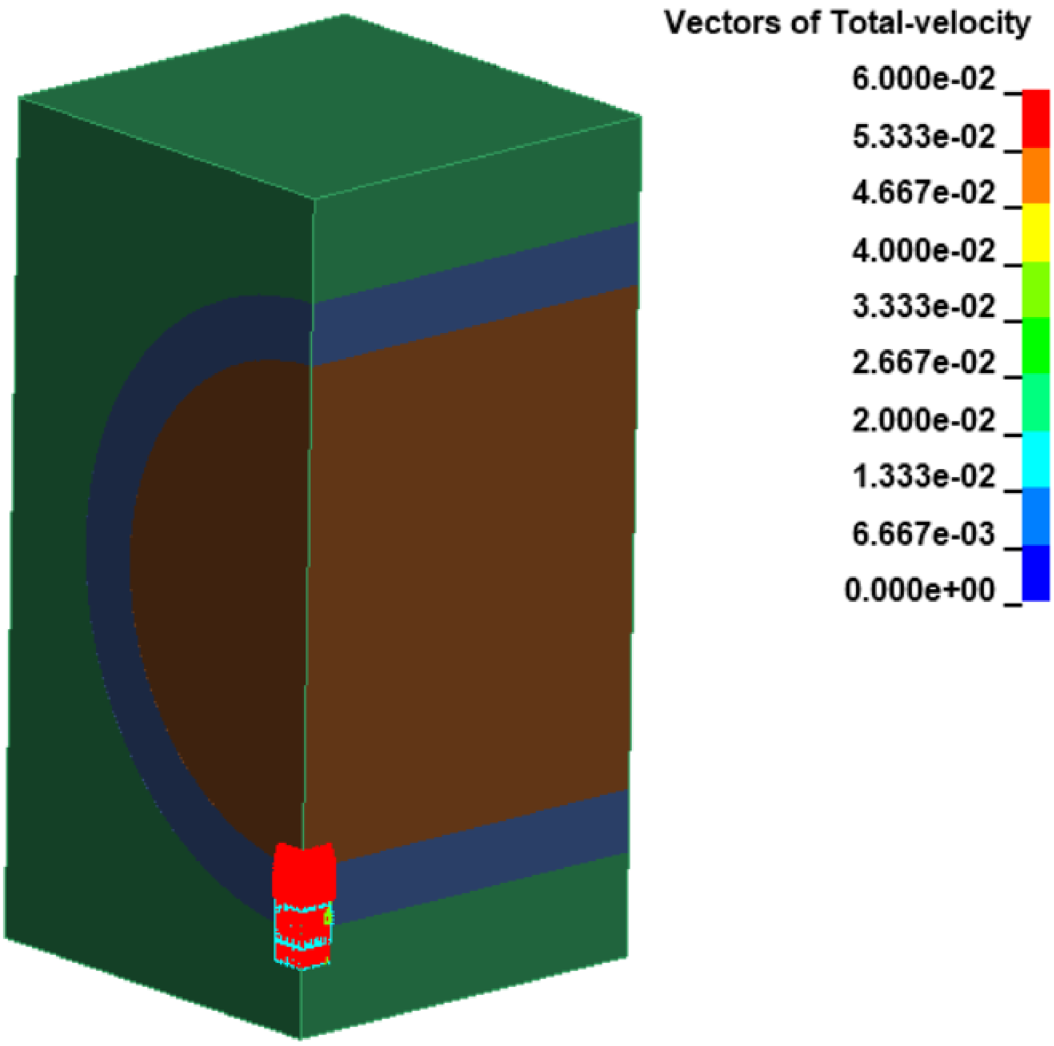

Fig.12: 3D Quarter symmetric ALE model set up

Same size of projectile and velocity used to present the model. In LS-DYNA with *Initial_volume fraction geometry problem set up can be created easily.

4.3.1 3D Quarter symmetric ALE model with Volume Fraction

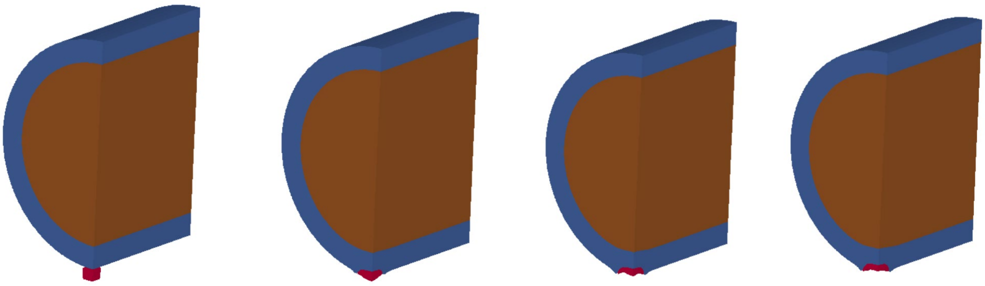

Fig.13: 3D Quarter symmetric ALE model penetration results (0-5-10-15 us)

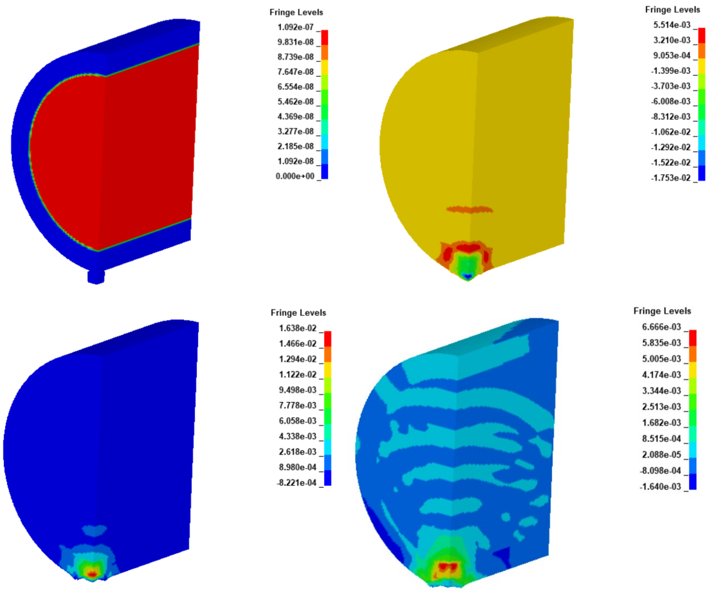

Fig.14: 3D Quarter symmetric ALE model pressure results (0-5-10-15 us)

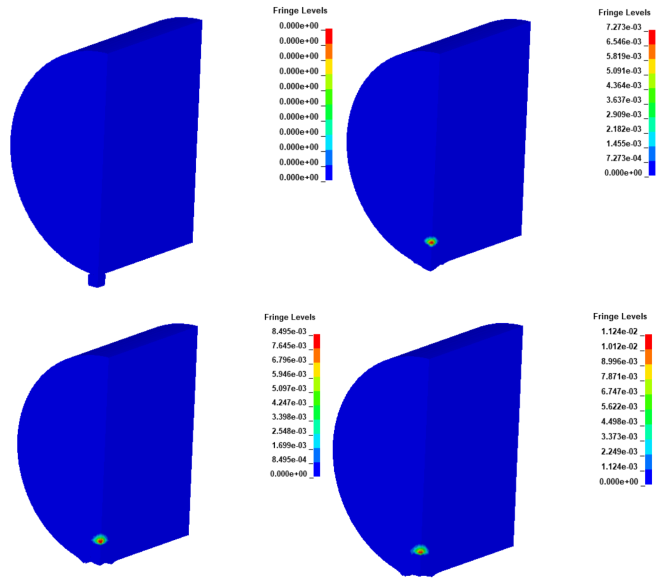

Fig.15: 3D Quarter symmetric ALE model burn fraction results (0-5-10-15 us)

4.3.2 3D Quarter symmetric Lagrange model with conventionally mesh

This part is left for future work. Although similar models have been analyzed with different geometries conventionally meshed models takes four or five times longer to model. To give brief example of our work we show a similar model mesh and results.

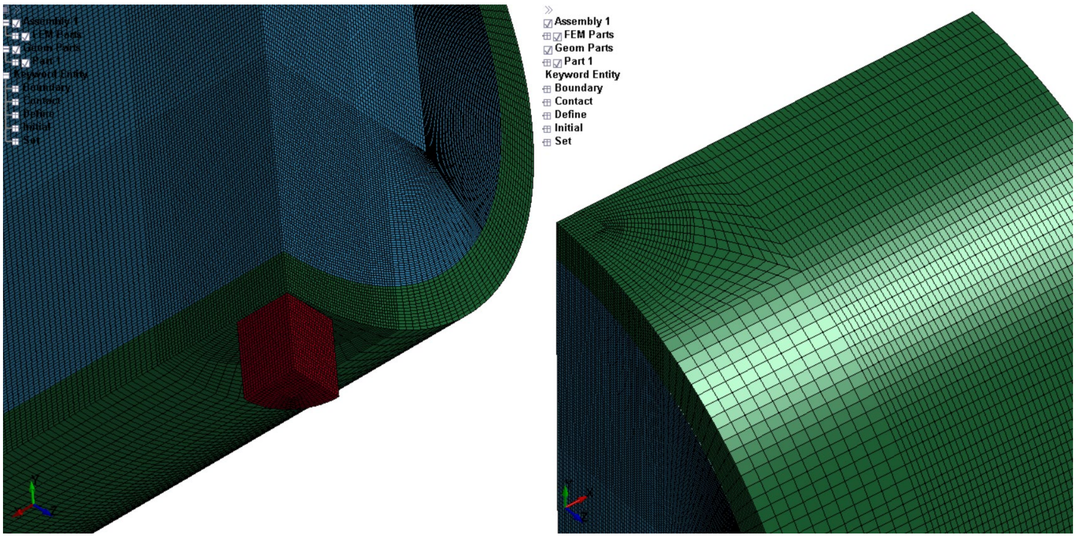

Fig.16: Conventianllly meshed lagrange model mesh

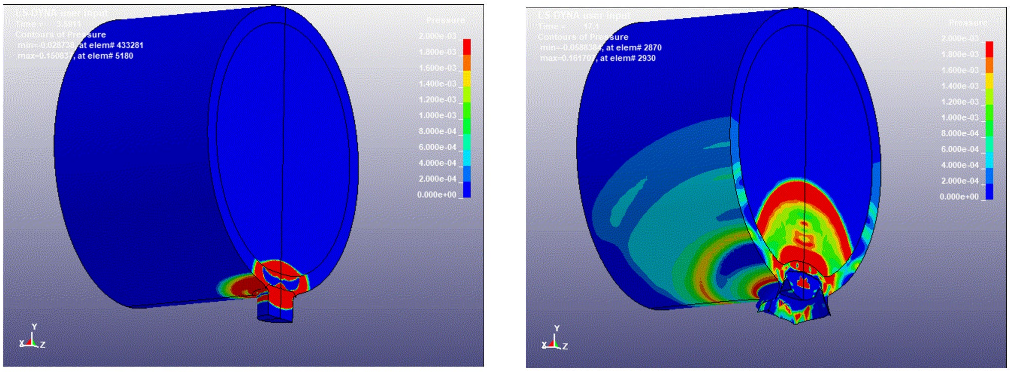

Fig.17: Conventionally meshed lagrange model pressure results

5 Design scenario results

In design scenario section we like to present different design and projectile velocities for a proper controlled blast. Fist model is same above the paper, small projectile which has a radius 0.32 cm with 0,06cm/us velocity, second one is small projectile with 0,12 cm/us velocity. Third scenario is big projectile which has a radius 0.64 cm with 0,06cm/us velocity. And fourth scenario is big projectile with high velocity.

5.1 2D Axisymmetric ALE small projectile with low velocity

Fig.18: 2D Axisymmetric ALE results of LS-DYNA (0-5-10-15 us)

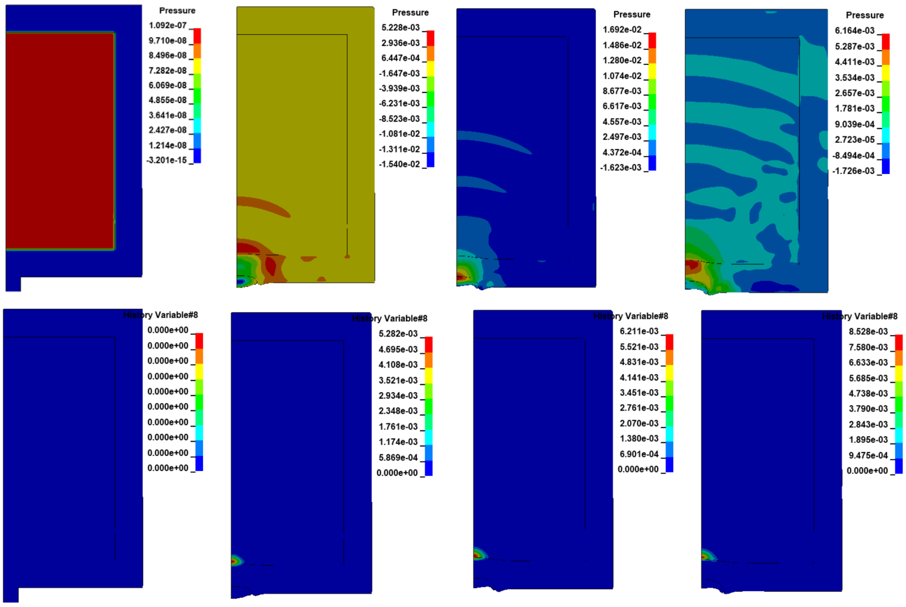

Fig.19: 2D Axisymmetric ALE results of LS-DYNA pressure and burn fraction below (0-5-10-15 us)

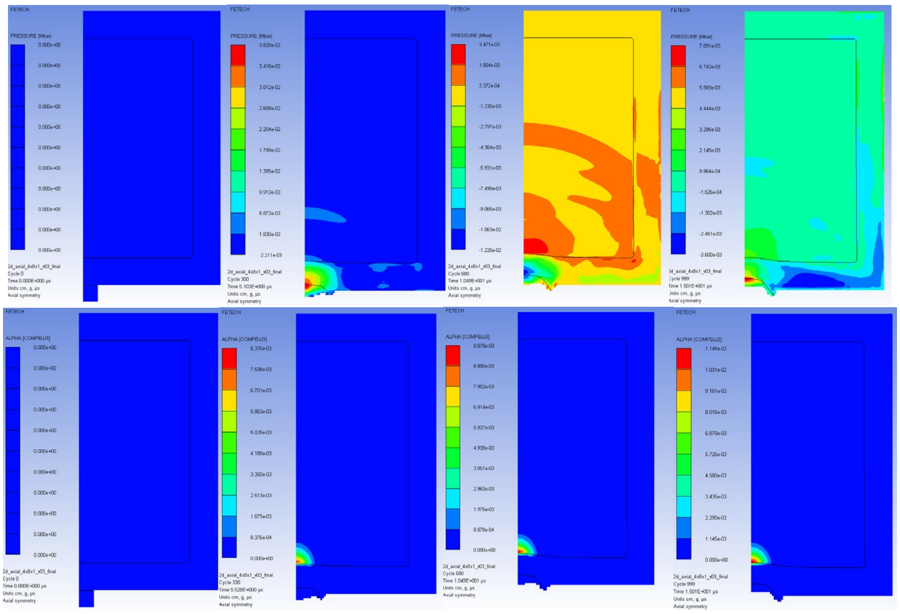

Fig.20: 2D Axisymmetric ALE results of AUTODYN pressure and burn fraction below (0-5-10-15 us)

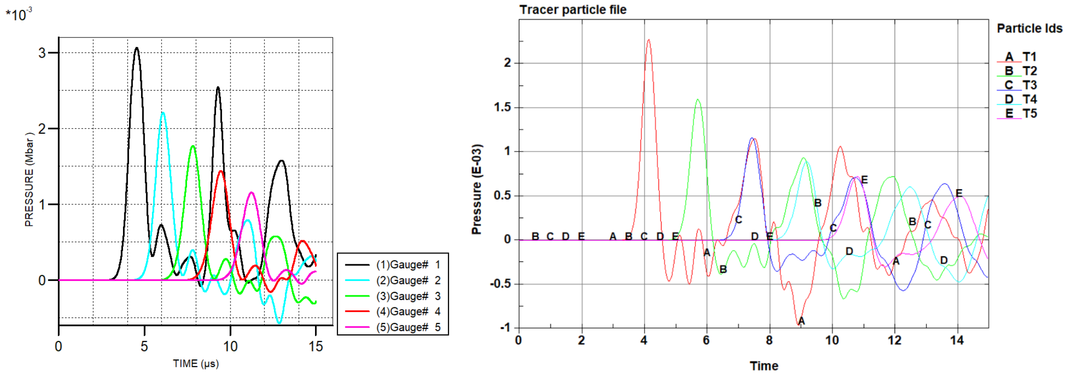

Fig.21: 2D Axisymmetric ALE results ofLS- DYNA vs AUTODYN pressure plot

5.2 2D Axisymmetric ALE small projectile with high velocity

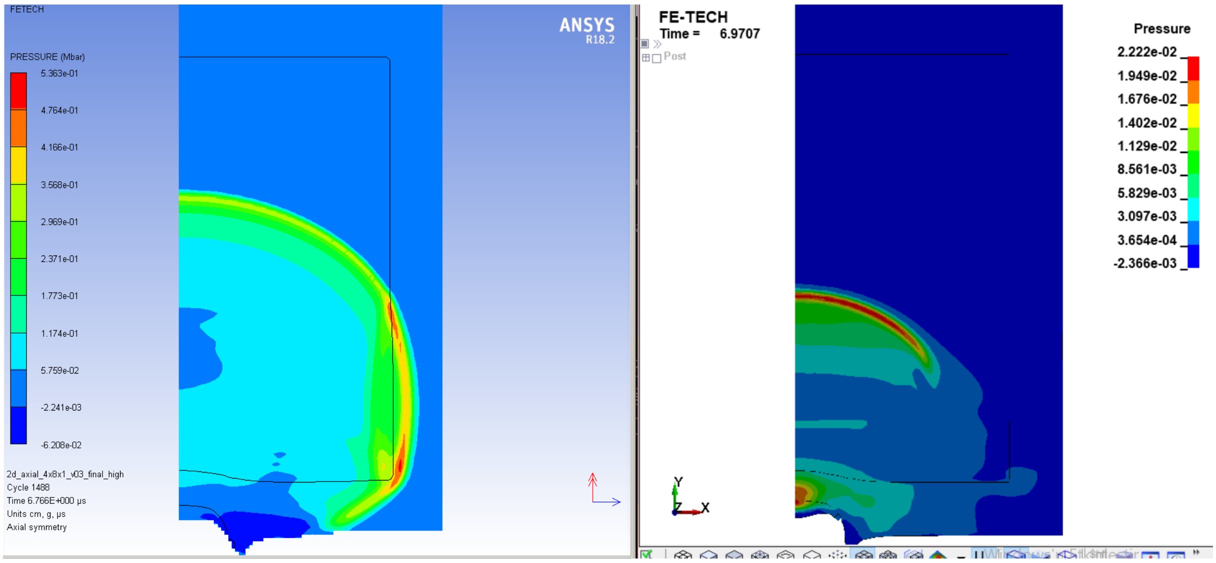

Fig.22: Pressure distribution AUTODYN on left and LS-DYNA on right

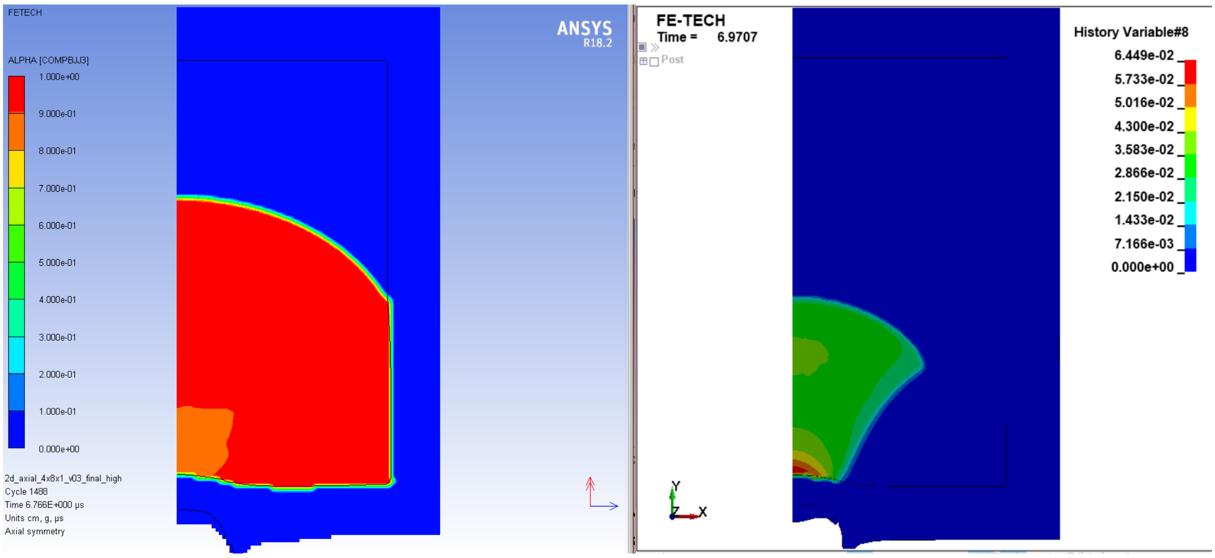

Fig.23: Burn fraction distribution AUTODYN on left and LS-DYNA on right

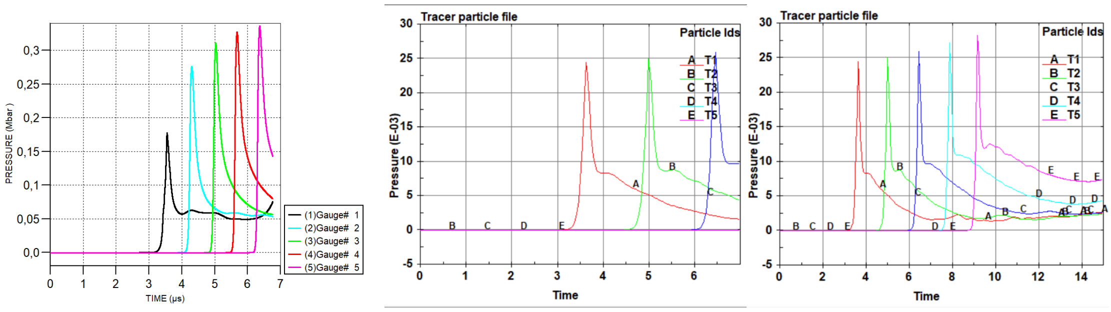

Fig.24: Pressure graph of AUTODYN on left and LS-DYNA on right

5.3 2D Axisymmetric ALE big projectile with low velocity

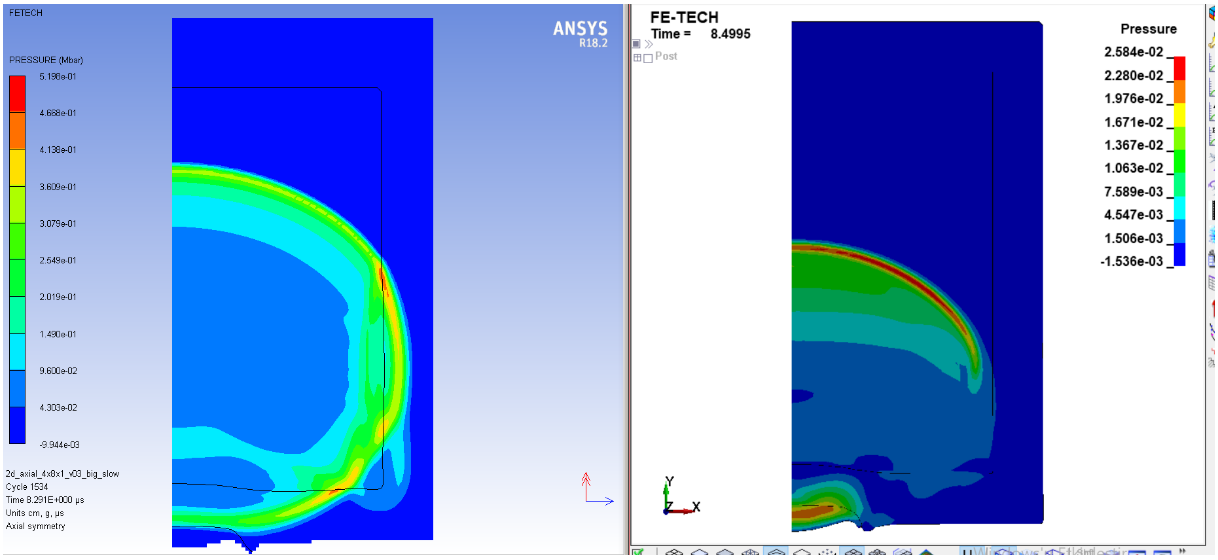

Fig.25: Pressure distribution AUTODYN on left and LS-DYNA on right

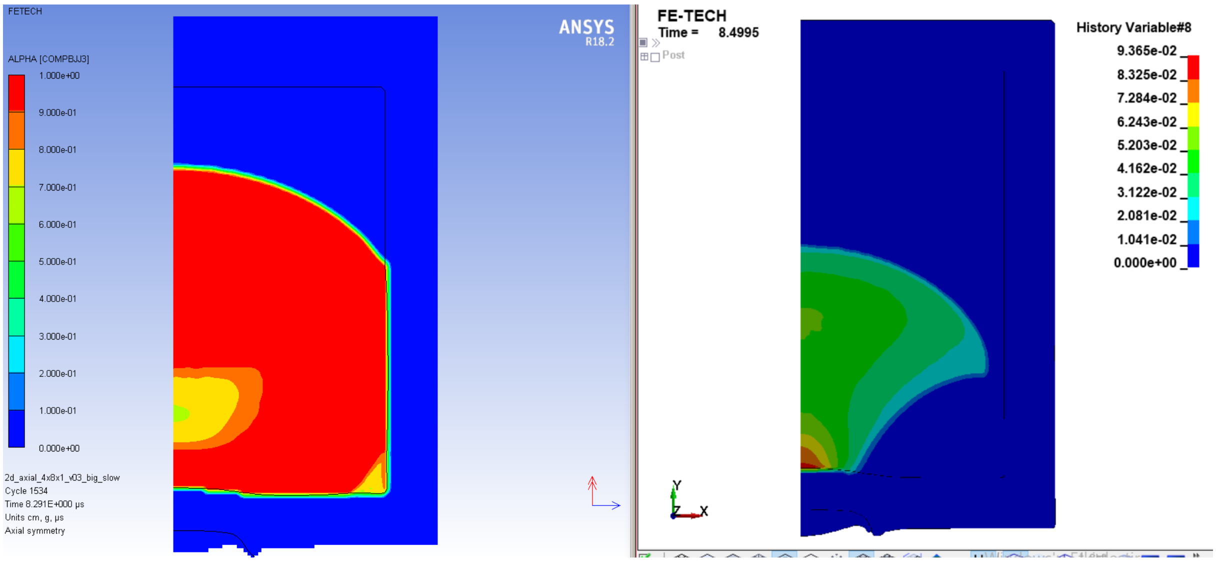

Fig.26: Burn fraction distribution AUTODYN on left and LS-DYNA on right

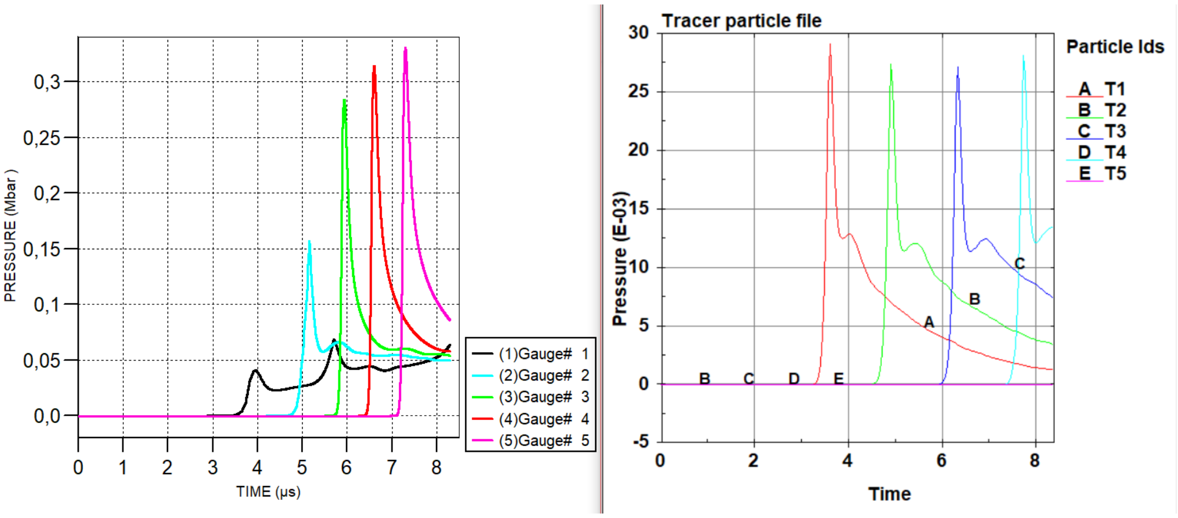

Fig.27: Pressure graph of AUTODYN on left and LS-DYNA on right

5.4 2D Axisymmetric ALE big projectile with high velocity

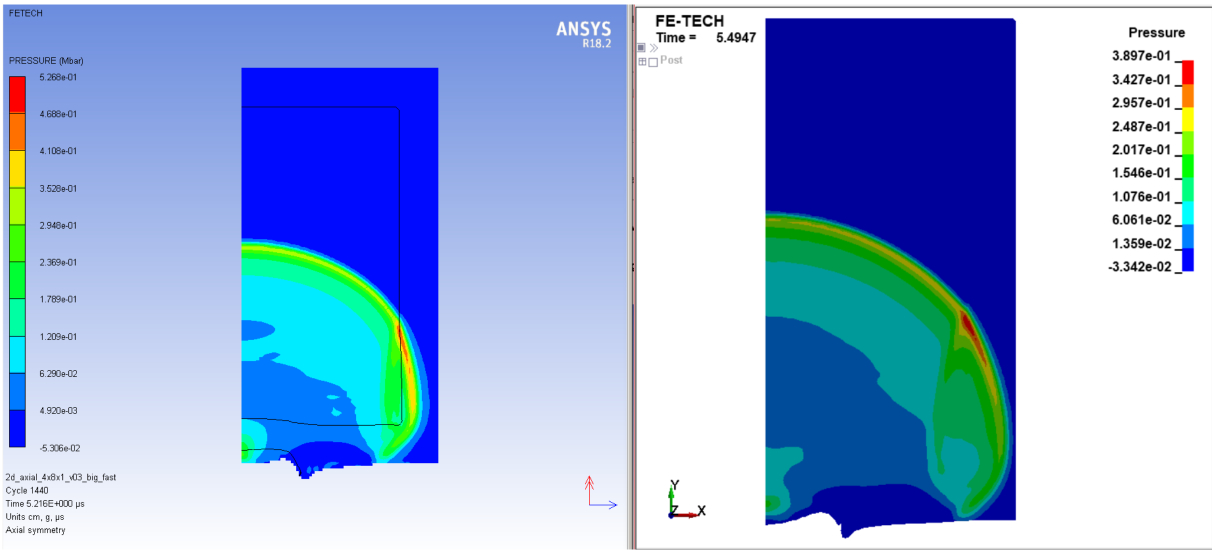

Fig.28: Pressure distribution AUTODYN on left and LS-DYNA on right

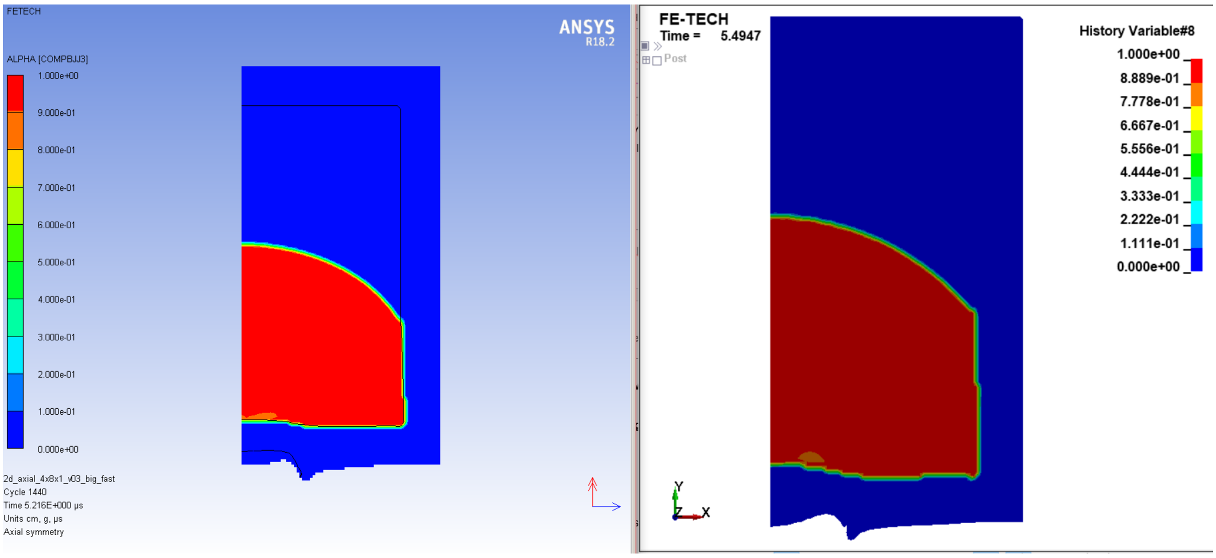

Fig.29: Burn fraction distribution AUTODYN on left and LS-DYNA on right

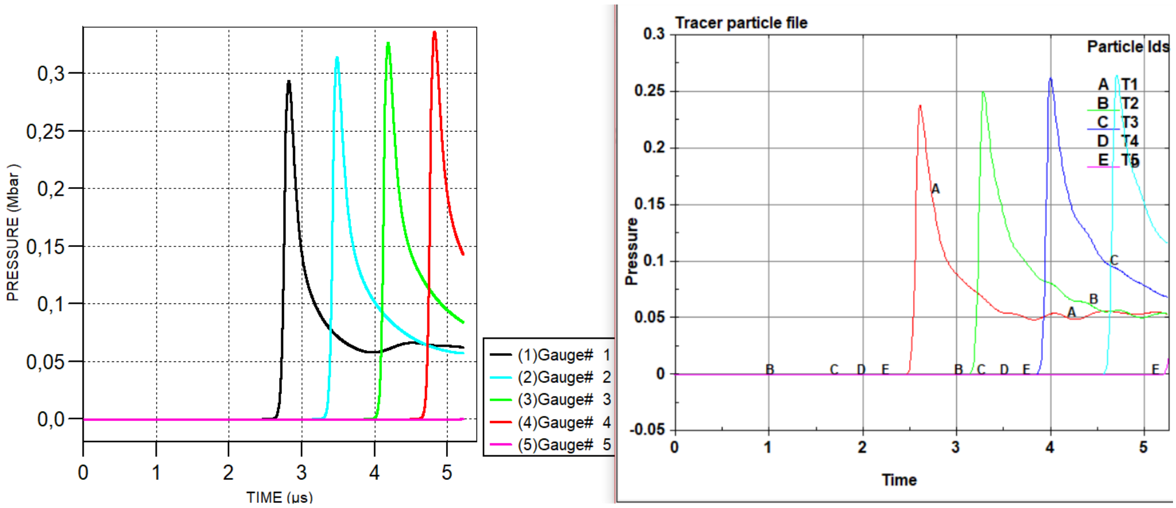

Fig.30: Pressure graph of AUTODYN on left and LS-DYNA on right

6 Summary

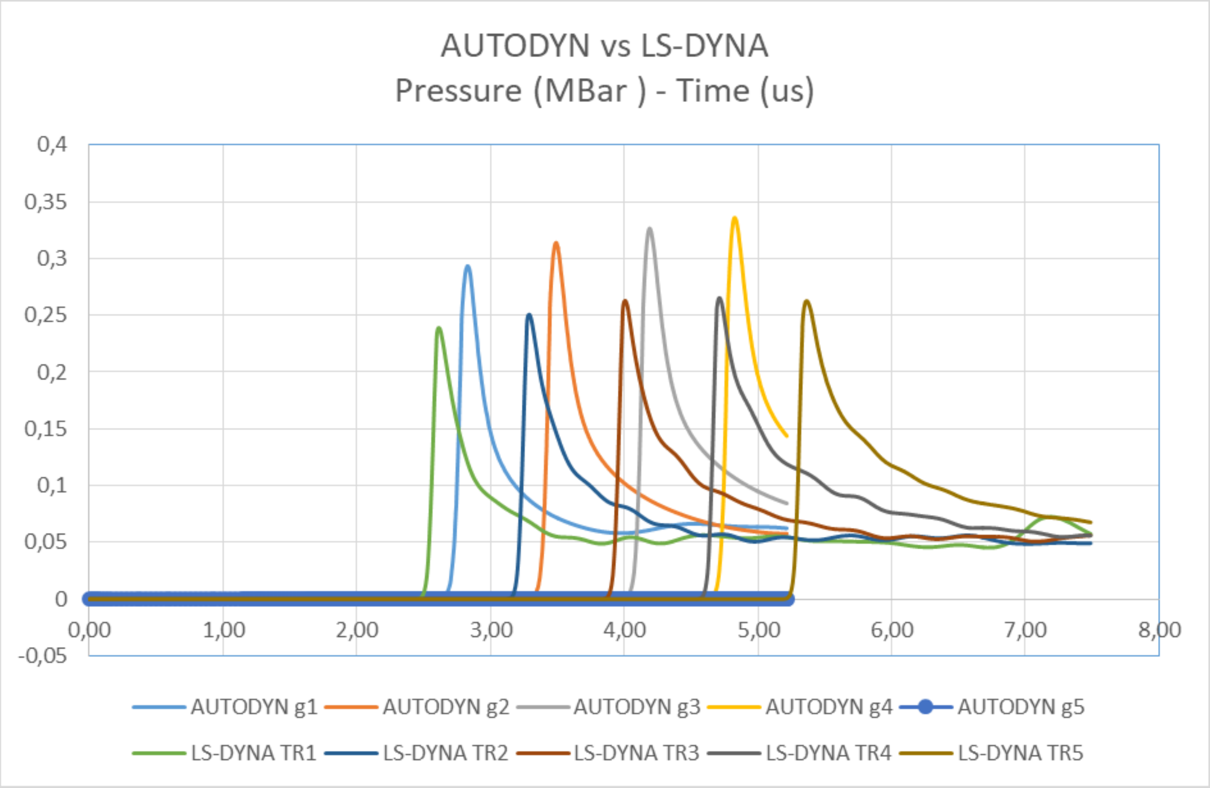

Fig.31: AUTODYN vs LS-DYNA pressure graph of the fourth scenario

As it can be seen from Fig 31 both codes represent good results in the final scenario. Results are %15 different from each other but both codes shows increasing pressures. This shows that in that state both codes shows that detonation occurs with same parameters. Besides both codes shows similar burn fraction shapes which is indicator of detonation.

Also in low velocity and small projectile case results seems reasonable, but the second and third scenarios there are some gray areas for both codes. But to design a controlled detonation both codes can easily be used.

7 Literature

[1] [Tarver.1997] Composition B model from C.M. Tarver February 1997
[2] LS-DYNA User's Manual RI-RII-RIII
[3] AUTODYN Explosive Initiation User's Manual Rev. 4.3 (Lee-Tarver Ignition & Growth)
[4] [Len Schwer] Impact and Detonation of COMP-B an example using LS-DYNA EOS: Ignition and Growth of Reaction in High Explosives
[5] [J.K.CHEN,HSU-KUANG CHING AND FIROOZ A. ALLAHDADI] SHOCK-INDUCED DETONATION OF HIGH EXPLOSIVES BY HIGH VELOCITY IMPACT, JOURNAL OF MECHANICS OF MATERIALS AND STRUCTURES Vol. 2, No. 9, 2007
[6] [FIROOZ A. ALLAHDADI, DAVID F. MEDINA, ERIC T. OLSON, and SCOTT R. JEFFERS] Simulation of impact induced detonation of AIM-120 A novel approach, August 1998