

# **A Brief Introduction to Coupling Load Blast Enhanced with Multi-Material ALE: The Best of Both Worlds for Air Blast Simulation**

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## **Summary:**

In this brief look at `LOAD_BLAST_ENHANCED` and Multi-Material ALE coupling, the LS-DYNA required keywords are explained and some of the key parameters are investigated using a simple example. Based on these simple examples some recommendations for LBE and MM-ALE coupling are provided.

## **Keywords:**

Air Blast, `LOAD_BLAST_ENHANCED`, Multi-Material ALE, coupling, advection

## 1 Introduction

The introduction of the ability to couple the engineering model for air blast (\*LOAD\_BLAST\_ENHANCED) with the Multi-Material Arbitrary Lagrange Eulerian (MM-ALE) solver, see Slavik (2009), offers several advantages over the use of either technique for air blast simulations.

A disadvantage of the \*LOAD\_BLAST\_ENHANCED (LBE) approach is that reflections cannot be accounted for, e.g. as would occur when a blast encounters the interior corner of a room. Similarly, \*LOAD\_BLAST\_ENHANCED cannot treat blast loads around an exterior corner or shadowing where a structure is between the blast and the target structure.

The chief disadvantage of the MM-ALE solver is the large air domain that typically needs to be included in the air blast model to mitigate boundary effects. The large domain's computational burden is further aggravated by the need to use quite fine mesh resolution to adequately resolve the air shock.

The combination of \*LOAD\_BLAST\_ENHANCED and the MM-ALE solver can be used to overcome some of these disadvantages. Consider the configuration shown in Figure 1. A bomb is located at a significant distance from a target which is not in direct line-of-sight of the bomb. Pressure pulses arriving at the target will be those reflected from the surrounding structures. If this simulation was to be performed with only the MM-ALE solver, then the large outer box, that includes a quarter of the bomb, would need to be included in the Eulerian mesh. However, using LOAD\_BLAST\_ENHANCED, with coupling to the MM-ALE solver, the two indicated outer surfaces of the much smaller Eulerian domain would be loaded by LBE and the interior blast wave reflections would be computed by the MM-ALE solver. In this example, the CPU saving would be significant as only about  $\frac{1}{4}$  of the larger Eulerian domain needs to be included in the coupled LBE and MM-ALE simulation.

In this brief look at LBE and MM-ALE coupling, the LS-DYNA required keywords are explained and some of the key parameters are investigated using a simple example. Based on these simple examples some recommendations for LBE and MM-ALE coupling are provided.

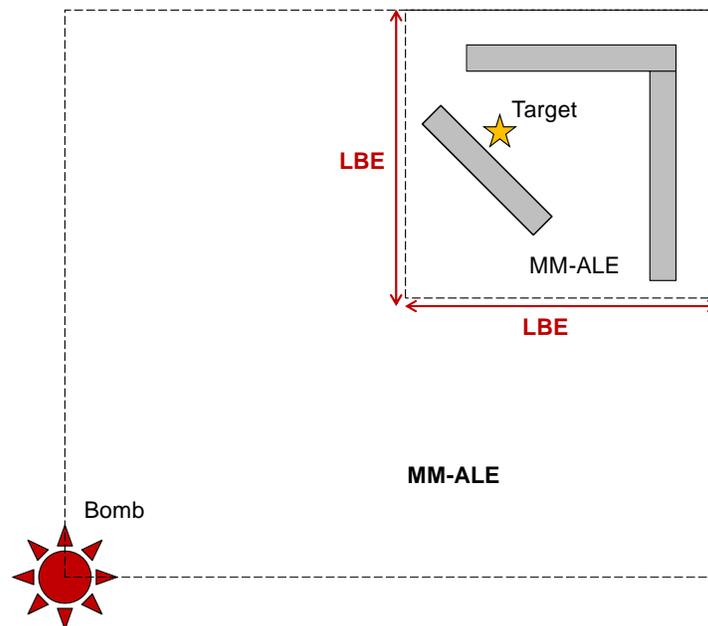


Figure 1 Schematic of advantages of couple LBE with MM-ALE.

## 2 Simple Free Air Blast Coupling Example

Before including structures, and associated blast wave reflections, in the demonstration of the LOAD\_BLAST\_ENHANCED coupling to the MM-ALE, the simpler case of free air blast coupling is examined.

### 2.1 Example Description

As shown in Figure 2, the simple example includes a 1.5 kg charge of TNT equivalent located 3 meters from a MM-ALE box of air with dimension 0.35 m in the horizontal direction and 0.3 m in the vertical direction.

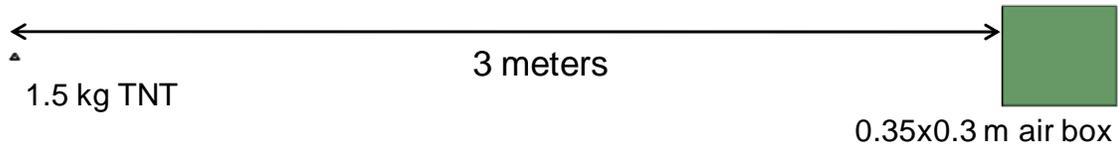


Figure 2 Simple free air blast example of an explosive charge and a MM-ALE box of air.

The air box is discretized into 9540 Eulerian hexahedra elements with dimension 3.33x3.33 mm, constrained in the out of plane direction, i.e. plane strain. The left most column of elements is identified as a separate part, with Part ID 99 and Section ID 99, defined to be Ambient ALE-3D, viz.

```
*PART
$ PID  SECID  MID  EOSID  HGID  GRAV ADAPT  TMID
   99,   99,  100,  100,   10,    0
*SECTION_SOLID
$  SID  ALEFORM  AET
   99,   11,    5
```

It is the AET=5 parameter that specifies the Ambient Element Type to be “Receptor for Load Blast Enhanced.” In general, an Ambient Element in the MM-ALE solver is a prescribed boundary condition, e.g. prescribed pressure in/out flow. The Section keyword parameter ALEFORM=11 indicates a Multi-Material ALE formulation.

The remainder of the air box is defined to be air with an external boundary pressure of 1 atmosphere, via the CONTROL\_ALE keyword parameter PREF=0.1 MPa, with Part ID 20 and Section ID 10

```
*PART
$ PID  SECID  MID  EOSID  HGID  GRAV ADAPT  TMID
   20,  10,  100,  100,   10,    0
*SECTION_SOLID
$  SID  ALEFORM  AET
   10,   11
```

and the Null Material MID=100 with Equation-of -State EOSID=100 provide the inner air at 0.1 MPa initial pressure:

```
*MAT_NULL
$  MID  RO      PC  MU  TEROD  CEROD  YM  PR
   100, 1.29e-6, 0.0, 0.0, 0.0, 0.0, 0.0
$
*EOS_Linear_Polynomial
$  EOSID  C0  C1  C2  C3  C4  C5  C6
   100 ,  0.0, 0.0, 0.0, 0.0, 0.4, 0.4, 0.0
$  e0  v0
   0.25, 1.0
```

The system of units used in this document is grams-millimeters-milliseconds.

The preceding is a standard definition of an air volume when using MM-ALE. Other than the use of ambient elements, not special treatment is required in the MM-ALE definition for the coupling to LOAD\_BLAST\_ENHANCED.

The bomb for the LOAD\_BLAST\_ENHANCED portion of the coupling is defined using two keywords, the standard LBE input:

```
*LOAD_BLAST_ENHANCED
$  BID      M      XB0      YB0      ZB0      TB0      IUNIT  BLAST
   1, 1500.0, -3000.0,  0.0,  0.0, -3.5e-0,  5,    2
$  CFM      CFL      CFT      CFP
   2.2e-3,  3.28E-3,  1.0,    145.0
```

A 1500 g TNT equivalent charge located 3000 mm away from the origin where the face of the air box has been placed, a bomb detonation time of -3.5 ms to allow the blast wave to arrive at the air box just after the simulation begins, user supplied system of units (g-mm-ms), and the flag for a free air burst.

The second required LBE keyword is where the coupling to the MM-ALE model is defined. The outer surface segments of the ambient elements have been defined as a \*SET\_SEGMENT with a SID=99, these segments are to be loaded by the bomb with BID=1 (defined in the above LBE keyword). The additional parameters are MM-ALE Part ID (ALEPID=99) of the ambient elements and a parameter SCLNRB to minimize reflections returning to the coupled ambient elements.

```
*LOAD_BLAST_SEGMENT_SET
$  BID      SSID      ALEPID      SCLNRB
   1         99         99         0.0
```

## 2.2 Comparison of Results with ConWep

In this section, the pressure history from ConWep (Hyde, 1988) is compared with the LOAD\_BAST\_ENHANCED pressure applied to the MM-ALE ambient elements. The size of the air box is increased to demonstrate the effects of the MM-ALE boundaries on the pressure histories. Two MM-ALE parameters are also investigated, the METHOD parameter that controls the advection algorithm and the use of the ALE\_MULTI-MATERIAL\_GROUP keyword to combine the ambient and air, i.e. no tracking of the interface between the ambient material and the air material.

### 2.2.1 MM-ALE Boundaries

As stated above, in air blast simulations the boundaries of the MM-ALE mesh need to be sufficiently far away from the area of interest. This requirement is not removed when coupling to LOAD\_BLAST\_ENHANCED is used, rather coupling with LBE minimizes the MM-ALE mesh required to transmit the blast to the area of interest.

In this section two air box geometries are considered, as shown in Figure 3, the small box 350x300 mm and a taller box measuring 350x600 mm. The pressure histories at the center of the boxes on the front face loaded by LBE will be compared with the ConWep pressure history.

Figure 4 compares the pressure history at the center of the small air box in the ambient layer with the corresponding ConWep generated pressure history. As should be expected, both pressure histories are identical as the prescribed pressure from LBE is based on the same formulation (Friedlander Equation) as ConWep. Note: all MM-ALE pressure histories in this document have been shifted to remove the initial 0.1 MPa atmospheric pressure, i.e. overpressures are plotted. Also, the time scale has been shifted by 3.5 ms to account for the TBO parameters in the LOAD\_BLAST\_ENHANCED keyword. The magnitude of the overpressure in this example, 0.108 MPa, is not large, but is sufficient to be called an air shock.

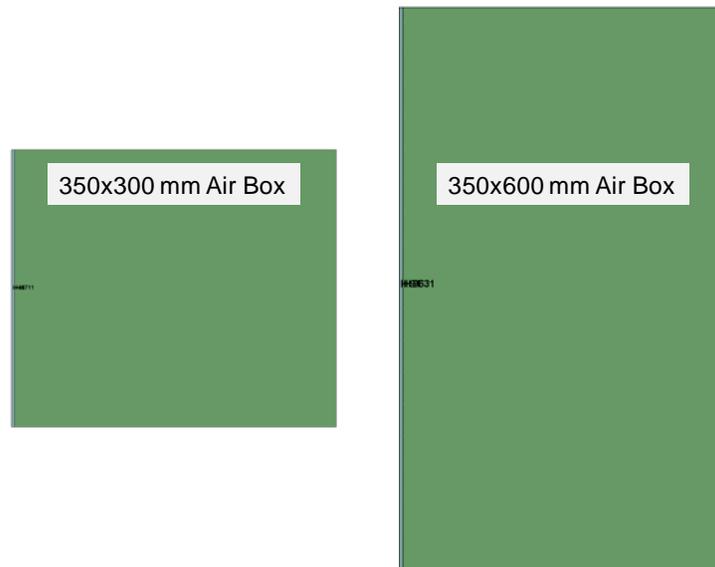


Figure 3 Small (left) and large (right) MM-ALE air boxes for coupling with LBE.

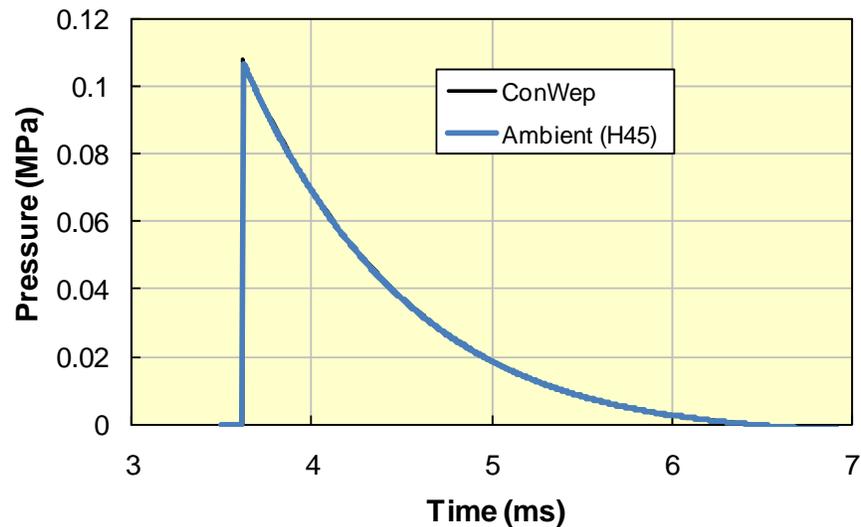


Figure 4 Comparison of ConWep and ambient element pressure history for small air box.

Figure 5 compares the same ambient element pressure history with the pressure in the adjacent air element. Since the center (integration point) of the adjacent element is only 3.3 mm from the neighboring ambient element, one would expect the pressure histories to be nearly identical; certainly the corresponding ConWep pressure history for the additional 3.3 mm location would be nearly identical.

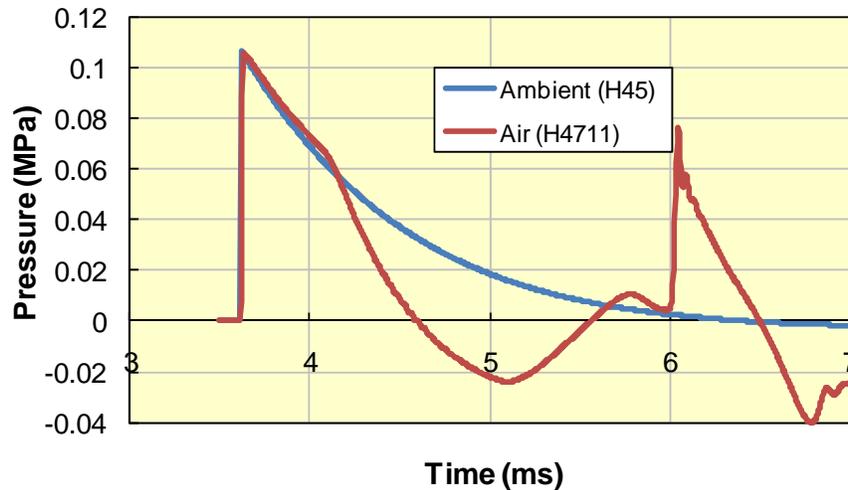


Figure 5 Comparison of ambient element and adjacent MM-ALE air element pressure histories.

The adjacent air element pressure history shown in Figure 5 closely follows the ambient element pressure history until about 4.16 ms when the pressure in the air element begins to rapidly decrease. This decrease is not a reflection from the rear of the air box, but rather an expansion wave from the top and bottom of the air box; the reflection from the back of the air box arrives at about 6 ms. The propagation of the expansion wave from the top and bottom surfaces, as well as the propagation of the incident pressure pulse toward the back of the box, is shown in the series of pressure fringes in Figure 6.

Since the three sides of the air box, other than the ambient layer on the left in Figure 6, are prescribed to have 0.1 MPa pressure boundaries, the ambient layer applied pressure near the top and bottom dissipates into these horizontal boundaries. The intended spherical pressure wave from the LBE source is thus modified at the top and bottom boundaries to a prescribed boundary pressure of 0.1 MPa. The result is a lack of pressure to support the spherical wave propagation, rather an expansion wave propagates from the top and bottom boundaries into the air box. It is this expansion wave that causes the rapid reduction in the pressure history in the air element shown previously in Figure 5.

The effect of the MM-ALE boundaries can in part be mitigated by increasing the size of the air box in the vertical direction, i.e. the large 350x600 mm air box. Figure 7 compares the pressure histories for ambient element with the small and large air box adjacent air element. With the larger air box the expansion waves from the top and bottom surfaces do not arrive until about 4.74 ms compared to the 4.16 ms for the smaller air box.

The conclusion is that while coupling LBE and MM-ALE does save considerable MM-ALE computational domain, the domain needs to be sufficiently large to propagate the LBE pressure without interference from the boundaries of the MM-ALE mesh.

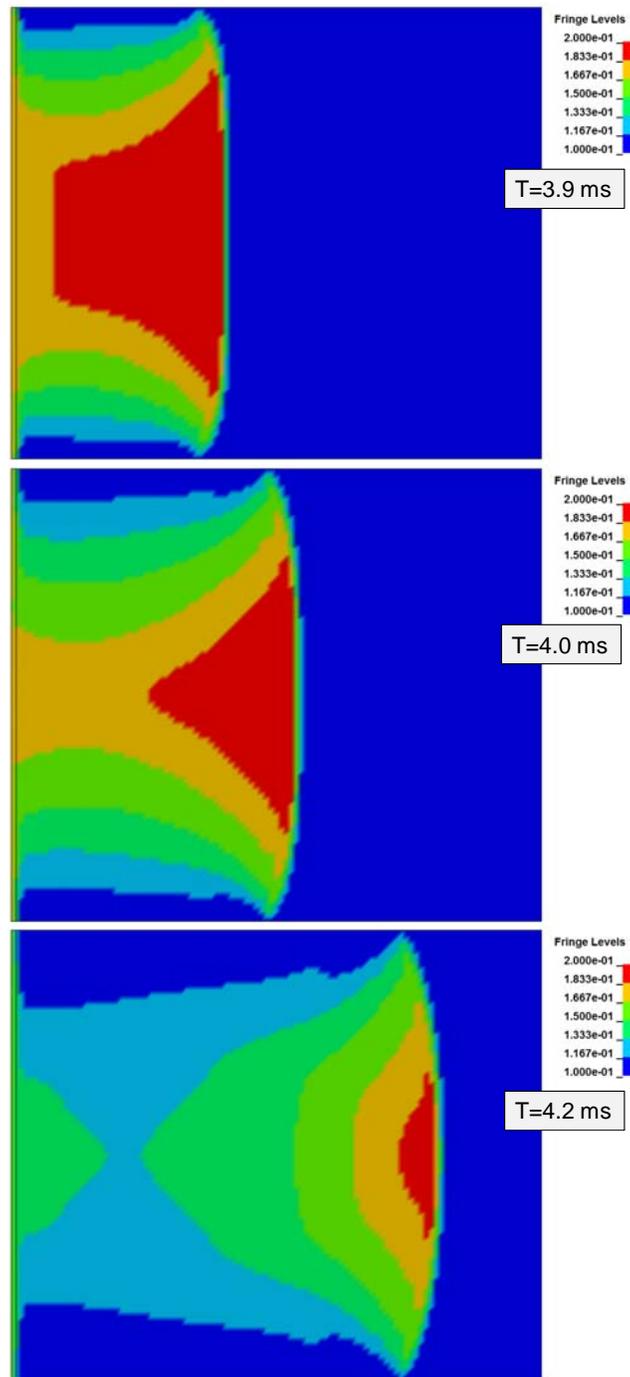


Figure 6 Time sequence of pressure fringes showing wave propagating from the ambient layer (left) into the air block.

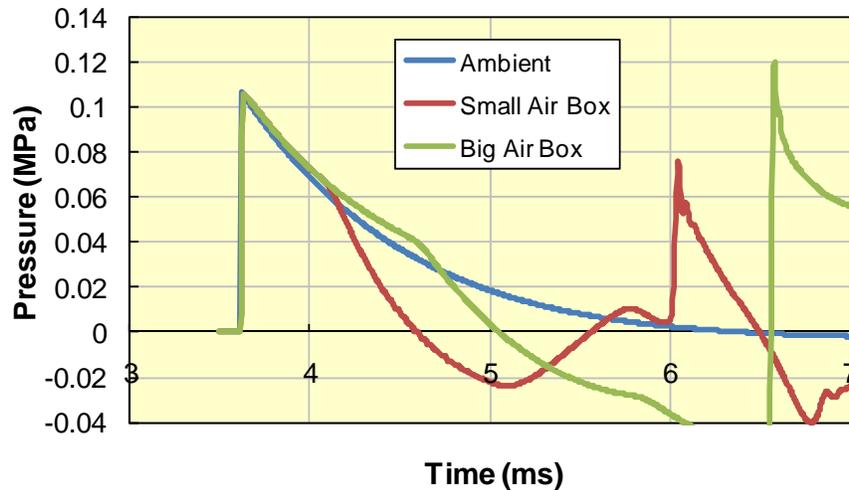


Figure 7 Comparison of pressure histories for ambient element with small and large air box adjacent air element.

2.2.2 Advection Method

The previous results were computed using advection METHOD=2 Van Leer plus Half-Index-Shift which is second order accurate, as specified on the CONTROL\_ALE keyword. The recommended advection algorithm for air blast is METHOD=3 Donor Cell plus Half-Index-Shift which is first-order accurate with total energy conservation. Although the present simple example is an air blast simulation, there is no explosive material modeled and associated explosive detonation products. The omission of the detonation products, means that METHOD=2 is recommended; it is always a good idea to run a predictive simulations with all three advection methods to assess the effect of the advection method on the result.

Figure 8 compares the pressure history at the center of the small air box in the ambient layer with the ConWep generated pressure history. Unlike the corresponding comparison for METHOD=2, recall Figure 4, the ambient element pressure history is not identical to the prescribed pressure from the LBE. The maximum pressure 0.092 MPa is about 15% less than the correspond LBE maximum pressure of 0.108 MPa.

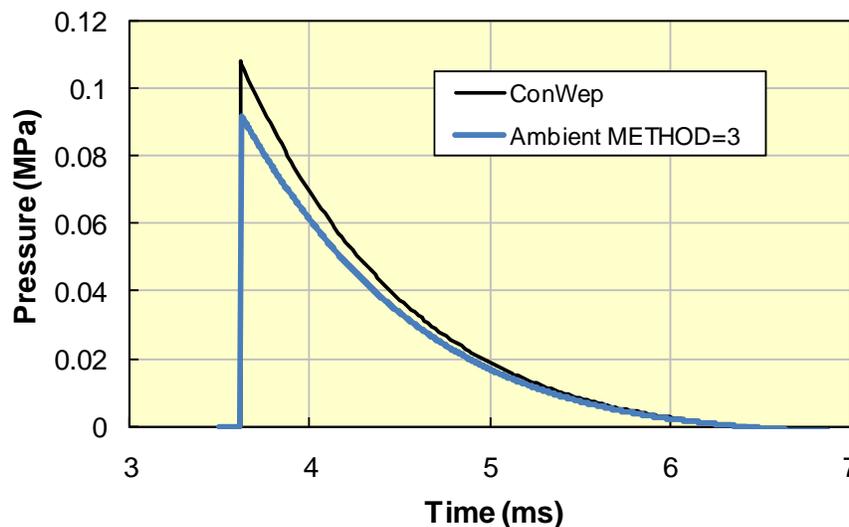


Figure 8 Comparison of pressure histories from ConWep and LBE with METHOD=3 in the ambient layer of the air block.

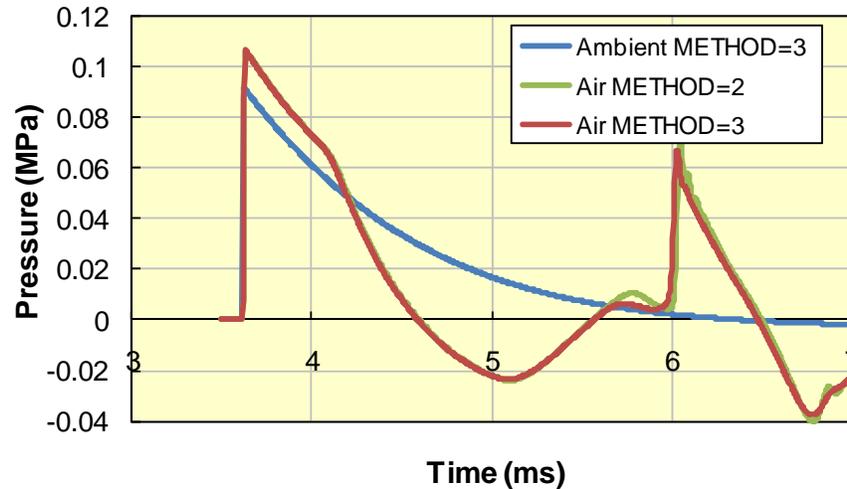


Figure 9 Comparison of the pressure histories in the ambient and adjacent air element for METHOD=3 and the adjacent air element for METHOD=2.

Although the ambient layer pressure with METHOD=3 is less than the prescribed pressure via LBE or equivalently ConWep, as shown in Figure 9, the pressure history in the adjacent air element is identical to the METHOD=2 advection method.

Why the ambient element pressure is affected by the advection method, but the adjacent air element is unaffected, and has a larger pressure, is left to the MM-ALE developers to explain. It is worth mentioning at this point that the LBE coupling needs to prescribe more than just the pressure in the ambient elements. In addition to the pressure history, the LBE coupling needs to prescribe the fluid (air) velocity to complete the boundary specification. The LSTC LBE developer, Todd Slavik, acknowledges that this velocity calculation is approximate.

Since METHOD=2 is second order accurate, and there are no detonation products present in the coupled simulation, it is recommended over METHOD=3.

### 2.2.3 To Group or Not to Group?

The previous calculations have been performed with ambient and air parts considered as one ALE Multi-Material Group (AMMG) via the keywords SET\_PART\_LIST and ALE\_MULTI-MATERIAL\_GROUP, viz.

```
*Set_Part_List
$ SID                Ambient & Air
  9920
$ PID1  PID2
$                99=Ambient 20=Air
  99,    20
$
*ALE_MULTI-MATERIAL_GROUP
$                99=Ambient 20=Air -> SPID=9920
$  SID  IDTYPE
  9920    0
```

By grouping together the ambient and air parts, the MM-ALE algorithm does not compute the interface between the two air parts during the simulation. The other option is to define a separate AMMG for each part, viz.

```
*ALE_MULTI-MATERIAL_GROUP
$          99=Ambient 20=Air
$      SID  IDTYPE
$      99    1
$      20    1
```

where the parameter IDTYPE=1 indicates a Part ID and the previously used IDTYPE=0 indicates a Part Set ID. Figure 10 shows a comparison of the fluid visualization via LS-PrePost for the cases of one (left) and two (right) AMMG. Typically, separate AMMG are used when it is desired to track the interface between disparate fluids in an MM-ALE simulation. The additional overhead of the interface reconstruction can be avoided if different fluids are lumped together in Part Sets. In the present case, since both the ambient part (fluid) and air part (fluid) are both air, there is no apparent reason to track the interface.

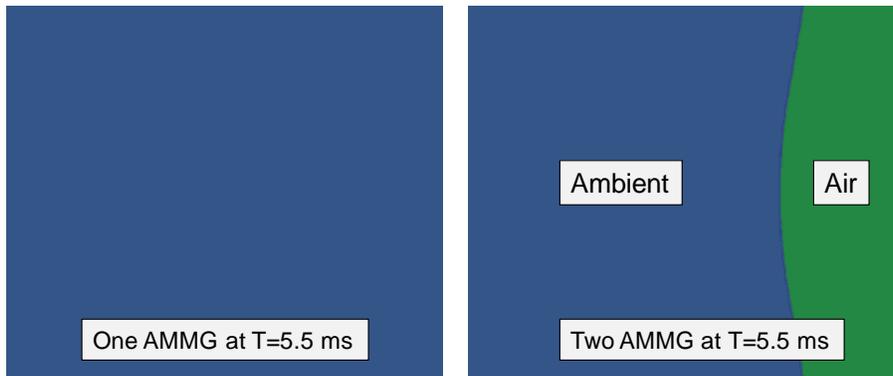


Figure 10 Comparison of fluid part visualizations at 5.5 ms for the two (left) and one (right) AMMG options.

However, using two AMMG in this simple example does cause an small initial pressure increase in the air element adjacent to the ambient layer, as shown in Figure 11. This pressure spike does not affect the remainder of the pressure pulse, so perhaps it is due to a mismatch in the velocity portion of the of the ambient element prescribed pressure and velocity.

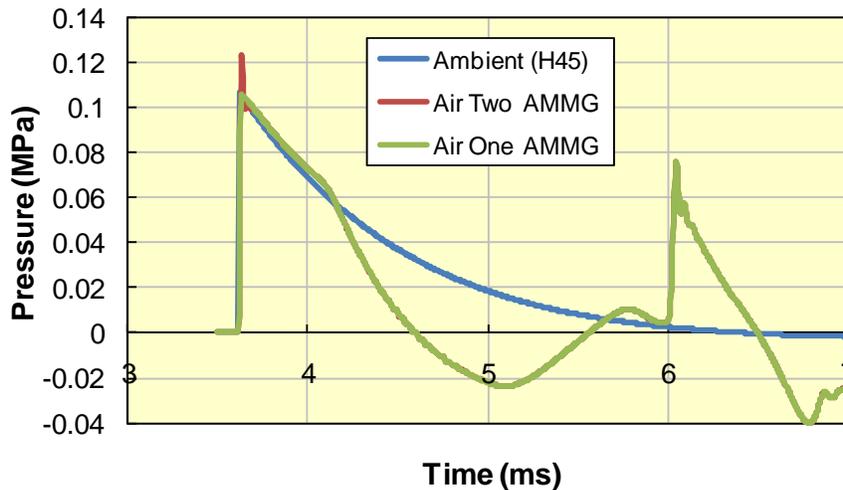


Figure 11 Pressure histories for ambient and adjacent air element with one and two AMMG.

It is recommend to combined the ambient and air parts as this will save some CPU time avoiding the interface reconstruction between the two types of air. It also can improve the fluid visualization in more complex simulations where other AMMG are present.

### 3 Summary

Based on the simple example presented in this document, the user of coupled LOAD\_BLAST\_ENHANCED and Multi-Material ALE can take advantage of the coupling to reduced the MM-ALE domain between the charge and the target, but still needs to include sufficient MM-ALE domain to avoid boundary effects near the target.

Advection METHOD=2, Van Leer plus Half-Index-Shift, produces the correct (ConWep) pressure in the ambient element, but the selection of either METHOD=2 or METHOD=3 produces the same pressure history in the adjacent air elements.

Combining the ambient part with the adjacent air part into one AMMG saves some computation time as the interface between the two air parts is not reconstructed. As with the advection method, there is a small initial pressure difference if the two air parts are tracked separately, but it does not affect the subsequent pressure history.

### 4 References

Slavik, T. "A Coupling of Empirical Explosive Blast Loads to ALE Air Domains in LS-DYNA," 7<sup>th</sup> European LS-DYNA Conference Salzburg Austria, 2009.  
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