SIMULATION OF A MINE BLAST EFFECT ON THE OCCUPANTS OF AN APC

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ABSTRACT

In this paper the use of LS-DYNA for the simulation of a mine blast load on an armoured personnel vehicle is presented with comparison to a full test. The investigated vehicle is an M113 APC with occupants seated in commercial seats. Different approaches to the numerical analysis of this complicated event are presented and results are compared. In particular the blast load is applied using the standard engineering model (CONWEP) because of the obvious computational advantages of this approach. However, a fully coupled finite element analysis simulating the interaction between the blast wave, the detonation gases and the vehicle was also performed. It is shown that the classical engineering model can severely underestimate the load on the APC. The use of the LS-DYNA component dummy models for the simulation of the occupants is also illustrated. The numerical simulations using LS-DYNA hydrocode were in good agreement with the experimental results. Those results show that the normal accelerations measured in the dummies pelvis are lower than the critical acceleration.

1 INTRODUCTORY REMARKS: APPROXIMATION LEVELS

1.1 LUMPED MASS VERSUS FINITE ELEMENT APPROACH

The lumped mass approach consists in a simulation involving rigid body elements and spring-damper systems. It is widely used for occupant simulation both in the automotive and the defence industries. The advantage is obviously the short running time of the simulation. With LS-DYNA we propose to start our investigation using a rigid body model of the APC. This should allow comparison with other lumped mass approaches if available and provide a conservative estimate of the kinetic energy transferred to the vehicle during the blast since no deformation is allowed. Once reasonable results are obtained at this level, switching the vehicle model to be deformable requires almost no data manipulation.

1.2 SIMULATION OF THE BLAST LOAD

Simulation of the blast load also allows different levels of approximation in the LS-DYNA package. The simplest way is to use the familiar CONWEP approach which has been implemented in the code as LOAD_BLAST. This allows for a full Lagrangean simulation of the problem and certainly generates the fastest solution. However, CONWEP seems highly reliable for the simulation of explosives at a rather large distance from the target and somewhat less suitable for simulating mine blasts. Therefore verification should at least be done using a full MMALE simulation of the blast load involving full modelling of air and detonation gases and coupling with the Lagrangean model of the vehicle. This simulation is pretty CPU-intensive but only the few first milliseconds of the blast need to be simulated and compared to CONWEP results.

1.3 SIMULATION OF OCCUPANTS, SEAT AND RESTRAINT SYSTEMS

The main goal of the simulation is to obtain acceleration levels in the dummy pelvic area. Therefore a rigid body dummy model can be considered sufficiently accurate. We have chosen to use a rigid body model of the hybrid-3 automotive dummy which is hardwired into LS-DYNA as the *COMPONENT_HYBRID_3 option. This is the simplest approach to modelling an occupant with the LS-DYNA package. The use of full finite element deformable dummy models is not considered in this paper but could represent the next level of accuracy in the simulations if more detailed injury criteria are to be investigated. The seat and seatbelt components were modelled from drawings using the HYPERMESH pre-processor and fixed to the M113 model with CONTACT_TIED options.

2 THE APC MODEL

The APC under consideration is an M113. The model contains 197732 solid elements and 300 shell elements, 196247 nodal points and 17 PID's. A global view of the model is shown in Figure 1 below.

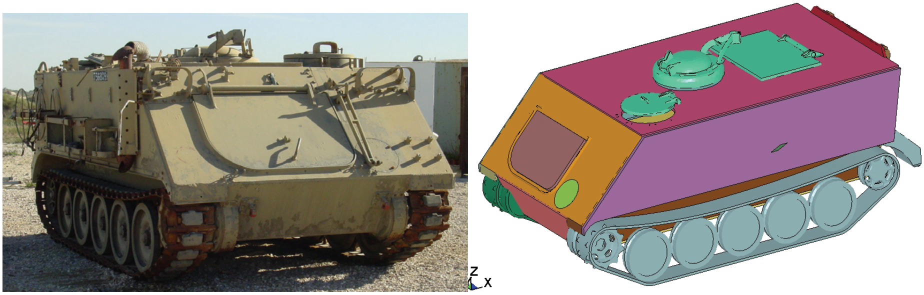

Figure 1: M113 APC CAD model

The model consists of a rigid superstructure and a deformable floor. The model of the deformable floor is shown in Figure 2 below

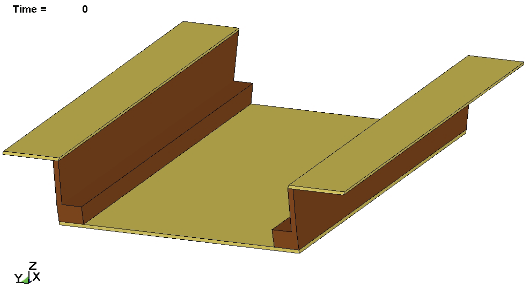

Figure 2: Deformable floor model of M113

A total of 15268 null shells were created additionally on the lower surface of the floor. The normal of these shells all point outward from the solid elements of the floor. These null shells were used to apply the pressure load to the APC. A PART_INERTIA card was used to introduce the correct vehicle mass of 12.5 tons and estimated values for the principal moments of inertia. By adding the parts of the deformable floor to the rigid body constituting the superstructure the complete APV model could easily be made rigid.

3 SIMULATION OF MINE BLAST LOADING ON M113 MODEL

3.1 6 KG MINE BLAST ON A RIGID VEHICLE MODEL USING CONWEP

The simplest level of approximation consists of a simulation of the mine blast on the fully rigid model of the APC, without occupants and applying the load using the CONWEP tool in LS-DYNA. In this case the entire structure is submitted to gravity and the blast load is applied to the null shells defined earlier. The coordinates of the charge are adjusted to be exactly under the CG of the M113. This will result in a nearly vertical motion of the APV. The parameters in the LOAD_BLAST keyword are adjusted to a surface burst for a charge of 6kg TNT equivalent.

The blast wave reaches the APC floor after 86 microseconds with a maximum pressure of 0.1446 [GPa]. Resulting vertical motion of the M113, z-velocity (vertical direction) and z-acceleration as a function of time for the rigid body representing the APC :

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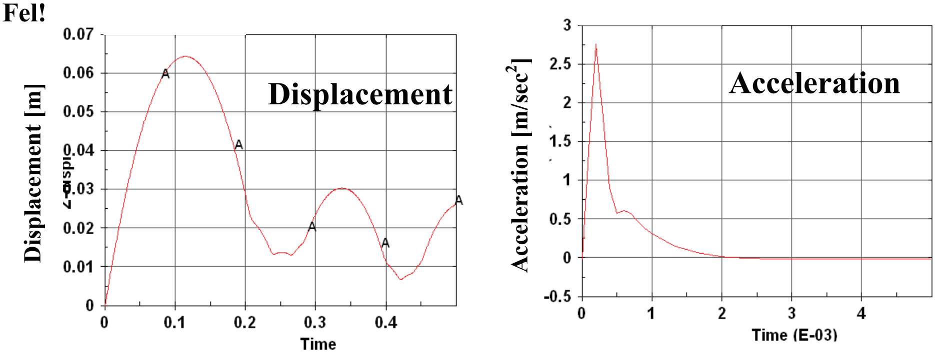

Figure 3: vertical acceleration & displacement of M113 APC

It can be seen that:

- a maximum acceleration of 270g is reached
- duration of the blast load is very short after 5 milliseconds the acceleration is constant and equal to -1g (gravity)

- after 2 milliseconds a maximum velocity of 1.10 m/s is reached, from then on the velocity decreases linearly in time
- contact with the ground is re-established after 200 milliseconds, the corresponding accelerations are very low compared to the original blast load

The predicted vertical displacement (about 6.5 cm) is confirmed as the simulation is continued to 500 ms (see Figure 3), however it is considerably less than what was observed in the corresponding experiment.

3.2 6 KG MINE BLAST ON A RIGID VEHICLE MODEL USING MMALE

To explain the discrepancy between test and simulation a coupled simulation was performed with the Lagrangean model of the M113 APC embedded in a multi-material Eulerian mesh used to simulate the detonation of 6 kg of explosive. In this simulation the floor slab was still assumed to be undeformable so the effects of the fact that the mine is buried were neglected. Also contact pressure was computed between the floor of the M113 (null shells) and the detonation gases of the explosive. Contact with the air was also neglected. The latter assumption can be partially justified by the fact that the distance between floor slab and M113 was only about 40 cm. Crucial to this analysis is the definition of the fluid-structure interaction where the null shells are constrained to move with the MMALE materials (air and explosive). The interaction is with the highest density fluid only (more robust simulation) and the penalty forces are computed from a user provided load curve. For 1 mm of penetration we reach a penalty pressure that corresponds to 1% of the Chapman-Jouguet pressure in the TNT. The solid mesh for air and explosive envelopes the entire M113 APC model. It should be noted that this is not necessary: it would be sufficient to cover the main area of interaction between the blast wave and the vehicle. Consequently an Eulerian mesh covering the APC up to mid-height would have been sufficient for this analysis.

The results of this analysis show a significant effect of the multiple ground reflections on the load upon the M113. The computed accelerations with CONWEP consist of a single peak of about 270 [g] whereas the coupled simulation gives a peak of roughly 1000 [g]. CONWEP predicts no sustained loading after the first peak whereas the coupled simulation shows acceleration values of up to 100 [g] after 4 milliseconds.

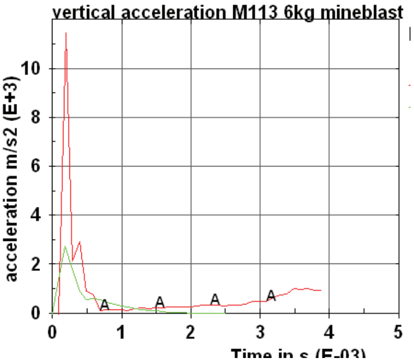

Figure 4: Vertical motion of a rigid M113 due to a 6 kg mine blast

The longer duration of the loading in the coupled simulation is attributed to a simulation of the ground reflections of the blast wave. It should be noted at this point that the mesh used for the air/explosive materials was rather coarse (characteristic length of about 6 cm) and a finer mesh would result in a more precise pressure estimates.

The coupled analysis was performed for 4 milliseconds only due to the long runtimes involved. However a vertical 'launch' velocity of 3m/s resulting in a vertical displacement of about 45 cm seems plausible from this analysis.

A contour of volume fraction for the explosive on the Eulerian mesh shows that no leakage occurred between explosive and the Lagrangean mesh of the M113 model:

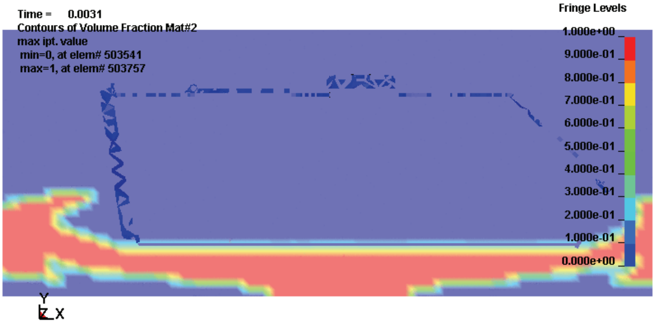

Figure 5: Contour of explosive volume fraction at 3.1 milliseconds

A sequence of 'fluid' plots shows the expansion of the detonation products in contact with the M113 APV :

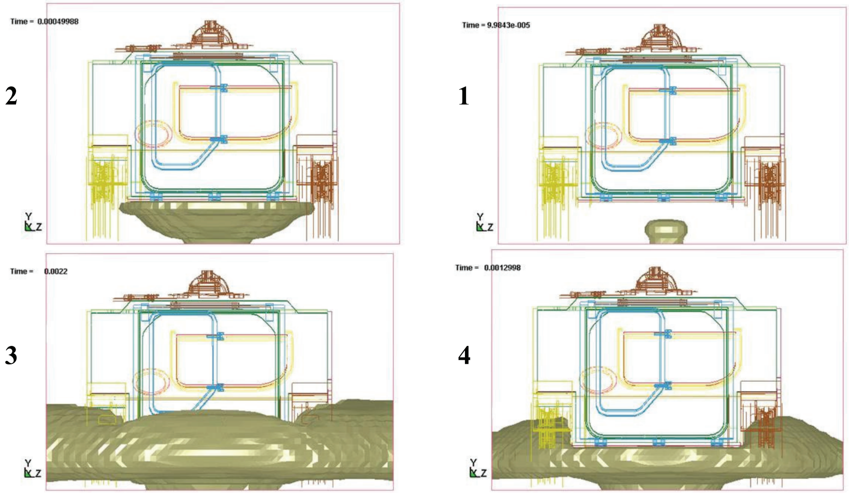

Figure 6: Expansion of detonation products

Figure 7: Expansion of detonation products in the test

4 MODELLING OF DUMMIES, SEATS AND RESTRAINT SYSTEMS

Rigid body models of the automotive Hybrid-3 dummy are hardwired into the LS-DYNA software and are easily implemented using the *COMPONENT command. A dummy in seated position is shown:

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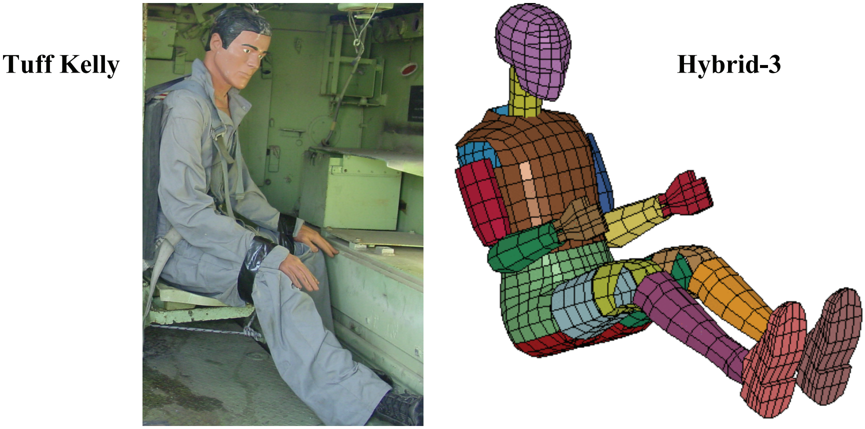


Figure 8: Dummy model after positioning

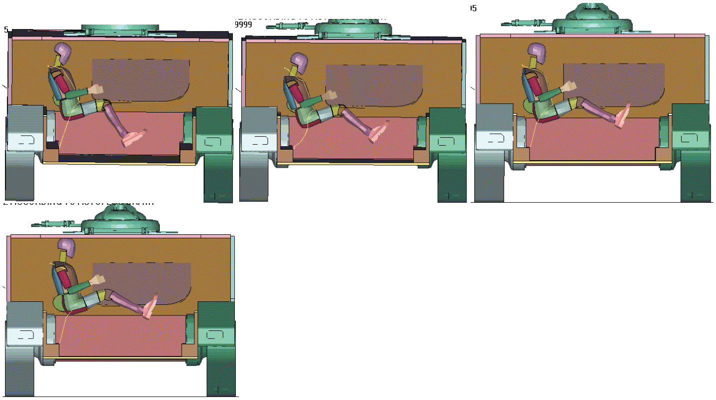
The dummy is positioned in a commercial seat which is modeled using shell, solid and beam elements

5 SIMULATION OF MINE BLAST LOADING ON MODEL OF M113 WITH OCCUPANTS

5.1 RIGID M113 APC MODEL

To achieve a simulation with rapid turnaround the M113 was modeled as a rigid body and the mine blast loading was applied using the CONWEP (LOAD_BLAST) option. The charge yields an initial vertical velocity for the vehicle of 3m/s which seems to correlate fairly well to experimental data. In this analysis the influence of the mine blast on the occupant will be examined. We are interested in particular in the accelerations at the pelvis level. The results will be compared later to a simulation taking the deformability of the floor of the M113 into account and to test results.

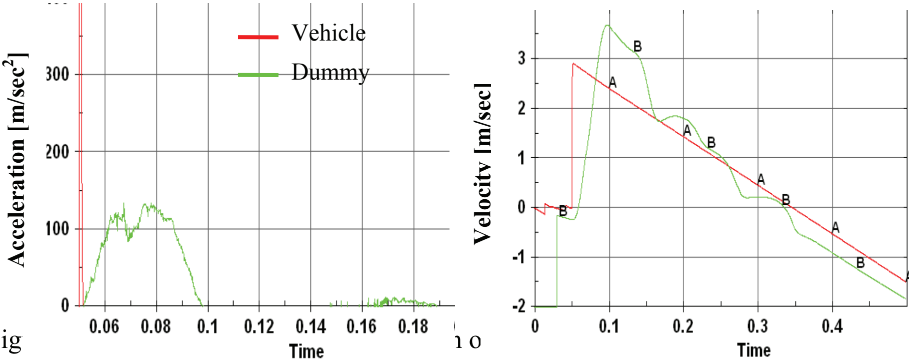
Some results of this simulation are shown below:



T=150 [msec] **T=100 [msec]** **T=50 [msec]** **T=0 [msec]**

Figure 9: Initial position of hybrid-3 dummy in the APV

A significant acceleration peak in the dummy pelvis shows duration of about 50 [msec] and a peak value of roughly 12.5 [g]. The maximum vertical velocity in the dummy pelvis slightly exceeds 3 [m/sec] measured in the rigid body representing the M113.



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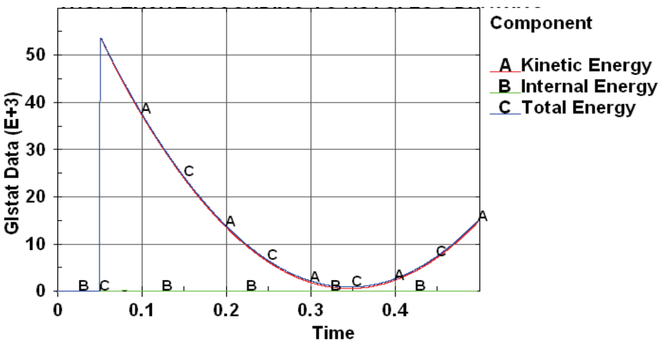

Figure 11: Energy balance of mine blast event

5.2 MODELING M113 APC WITH DEFORMABLE FLOOR

The modifications to the previous data decks necessary to consider a deformable floor in the M113 are fairly small. A material card for the armored steel of the floor plates must be added. In the Johnson-Cook material definition for the floor parts, no failure option was used. This was justified a posteriori by low plastic deformation in the floor panels. This could be due to the high yield strength of the material (1 GPa). Also the *PART_INERTIA card is modified, the mass is reduced in order to ensure that the total mass of the model is unaltered.

Some results of this analysis are shown below.

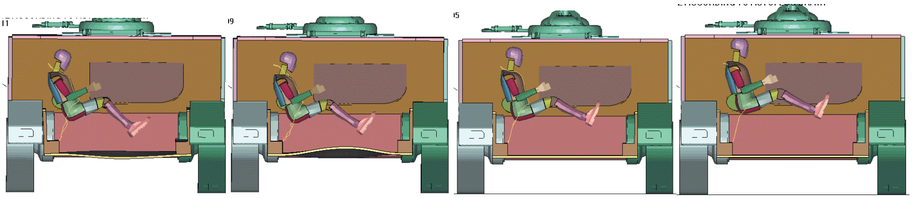

Figure 12: M113 model with deformable floor

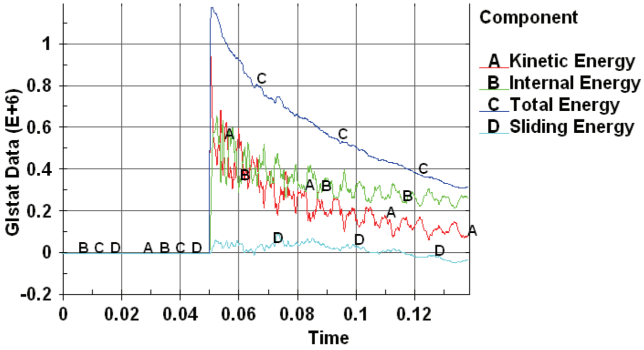

Figure 13: M113 model with deformable floor, energy balance

The predicted maximum acceleration of the dummy pelvis is about 1.5 g in this model, a rather significant increase with respect to the rigid model of the APC. This can be explained by the smaller rigid body mass of the upper part of the APC to which the seat is attached.

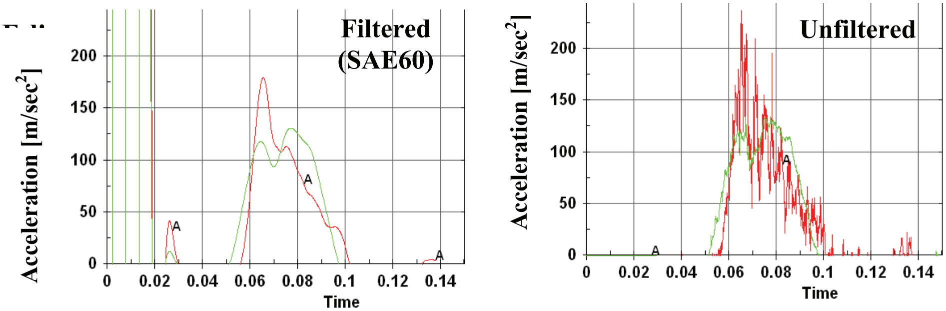

Figure 14: Accelerations in dummy pelvis (comparison rigid versus deformable APC)

In the plot of vertical velocities the frequency of the floor can be seen to influence the velocity of the upper part of the APC.

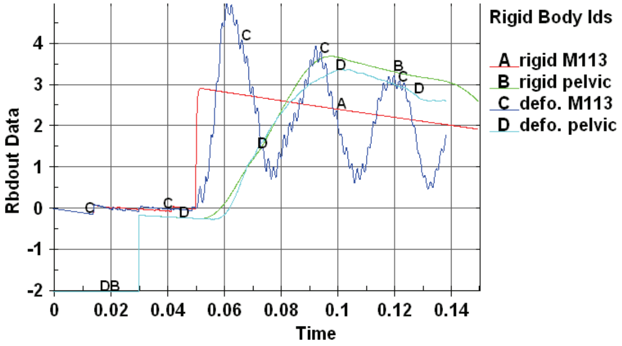

Figure 15: Vertical velocities of dummy pelvis and M113 rigid body part (comparison rigid versus deformable M113 model)

6 SUMMARY AND CONCLUSIONS

A number of approaches to the numerical assessment of the influence on the occupant of an APC under a mine blast have been shown in this report. In particular detailed and simplified approaches have been examined for the application of the blast load, the modeling of the seat and the representation of the APC. Two main conclusions can be drawn:

1. The consideration of the deformability of the APV in the simulation is important since the influences on the dummy acceleration values are significant.
2. If simplified approaches such as CONWEP are used to apply the blast load, scaling the charge by a factor 2-3 to take further ground reflections into account seems reasonable.

It should further be said that in this study we have used the rigid body dummy model of the automotive hybrid-3 dummy. This model is hardwired into the software and there fore very easily activated and positioned.

However, in actual testing a different dummy (Tuff Kelly) is used and differences in mass and geometry may result in different acceleration values being measured.