Numerical simulation of ground impact after airdrop

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ABSTRACT

The airborne forces of many countries use honeycomb paper as energy damping material (EDM) for heavy cargo airdrop. Its roughly constant crushing resistance makes the dimensioning of the kinetic energy absorber layer quite easy.
Yet the velocity and attitude of a parachute at ground impact is variable, due to weather conditions, or undamped pendulum movement of the load under the parachutes. Those parameters have a big influence on the shock level generated at ground impact. Since ground and flight testing is long and expensive, the Flight Test Centre (CEV) of the French MoD has been developing simulations tools to evaluate the EDM design efficiency for all impact conditions at the rigging's draft design level.
In 2003, the CEV definitely chose LS-DYNA for that kind of simulation and proved the consistency of the results for Shock Response Spectrum (SRC) prediction and comparison.
The paper presents the modelling work made for the EDM an application results for ammunition and vehicle airdrop.

INTRODUCTION

1. Airdrop :

Heavy cargo airdrop includes ammunition or vehicle airdrop applications. After exiting the lifter aeroplane, the load experiences a first shock as the parachutes open, then a second as it impacts the ground.
The load has to be fitted to survive those shocks, out of which the second is the hardest. The cargo usually laid on a platform fitted with EDM known as shock absorber pads, then rigged on the platform. The EDM has two main functions : adapting the platform to the load's geometry when it is not flat, and absorbing the kinetic energy at ground impact.

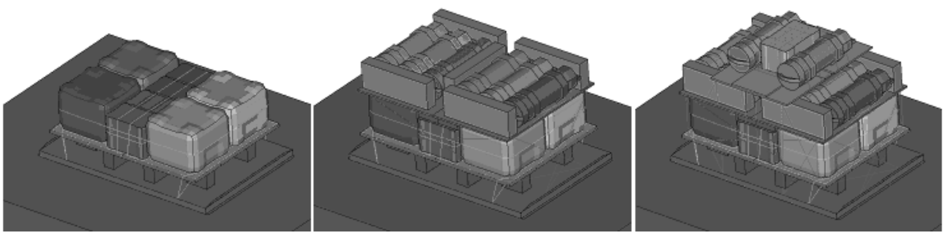

Fig.1 : Fitting for airdrop of a man portable missile weapon system. Layer 1 :4 firing posts and 4 lenses. Layer 2 : 6 missiles. Layer 3 : 2 missiles and 1 toolkit.

2. Cargo fitting :

Ammunition and weapon system containers are usually stacked in a multiple layer load, each layer being tied on a plywood stress repartition layer. The whole bundle is rigged with nylon ropes, belts and nets in order to survive the parachute opening shock. The EDM dimensioning is based on energy considerations. Since the honeycomb paper has a roughly constant resisting force, crushing pressure times EDM surface times EDM working length equals the kinetic energy at ground impact plus the load's centre of gravity potential energy. The deceleration is expected to be roughly uniform and stationary if the impact is flat (horizontal platform on horizontal ground).

3. Variable results :

Yet various parameters can change the shock level. First, the velocity of the load before impact can vary (typically sink rates 5 to 9 m/s and horizontal components ut to 10-12 m/s). Altogether, the impact is not necessarily flat, due to a sloped ground or load pendulum movement under the parachute(s). Finally, the EDM resistance is in fact speed-dependant, and can vary depending on the stocking conditions of the material, humidity, etc ... These are the "obvious" causes of the variations observed in measured Shock Response Spectra (SRS) between two different airdrops of similar loads. There are other causes of SRS variation, linked to the internal structure of the load itself (actual stiffness of the boxes, rigging's pre-tension, assembly precision, internal dampers pre-crushing) that will not be discussed in this paper.

4. Paper purpose :

The purpose of the authors is to show that LS-DYNA gives consistent results in terms of SRS level caused by ground impact, and allows to analyse the effect of

- variations of sink rate
- variations of horizontal velocity
- variations of load attitude or ground slope
- manufacturing tolerances for the EDM

in order to optimise cargo fittings for airdrop.

MODEL PRESENTATION

1. The mesh :

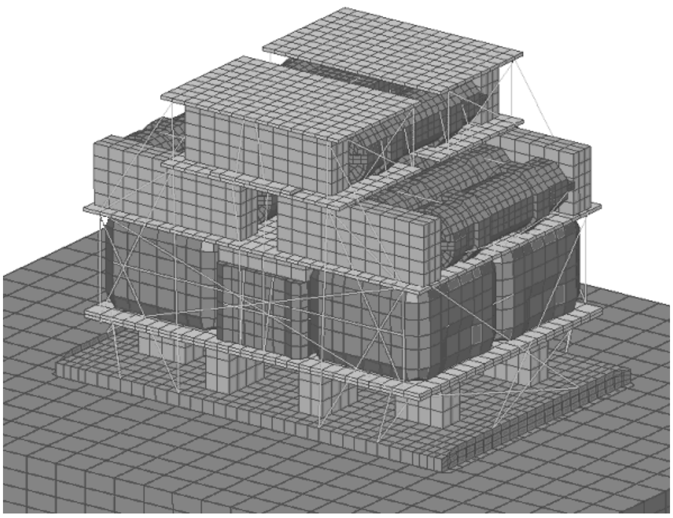

Fig. 2 : Mesh model showing bottom to top : ground, airdrop platform, EDM pads, 2 plywood layers, weapon system containers, plywood, ammo containers, plywood, ammo and toolkit containers, plywood. The sides of the 2nd and 3rd layers are padded with Honeycomb EDM too. Various kinds of rope and belts are used to rig the load.

The model mesh is made with only solid and seatbelt elements, except for two rigid shell parts representing the aluminium guides on both lateral sides of the platform.

Using solid elements for the plywood parts may seem surprising, yet proved to have a few qualities that had us prefer those to shells and thick shells :
- Ease of use of imported geometries, with no offset management or node order trouble.
- Better stability of contact algorithms.

Our purpose being to allow the nearly automatic generation of finite element model by non – expert operators, these qualities were enough to make us prefer solids to shells.

The platform and plywood plates are modelled with fully integrated solid elements formulation 2 (giving a stiffness in flexion even with only 1 layer of elements in the thickness) and an elastic material giving the correct stiffness in flexion, which is the only important strain mode in these parts in our simulations.

The rigs are modelled with seatbelts, with a linear elastic behaviour and a maximum resisting force before failure..

The weapons system containers are first modelled with rigid materials, with their actual global mass density.

The EDM is modelled with fully integrated solids, and a honeycomb type 26 material.

2. Material formulation :

The only material that needed modelling efforts is the EDM honeycomb paper. A set of static and dynamic experiments have been undertaken by the CEV since 1998 to fully characterise its static and dynamic behaviour, both in axis and out of axis.

The result showed a dynamic dependence of the resisting force in the range of strain rate observed in airdrop application. This dependence is related mainly to the air imprisoned in the honeycomb cells, that resists to the pressure exerted on the EDM pads.

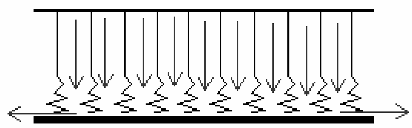

Fig. 3 : Schematic representation of air exiting the honeycomb paper during the crush through narrow interstitial areas.

Indeed, the volume of air imprisoned in the EDM only has a very small area between two honeycomb layer to leak out, and viscous effects oppose significantly to the leakage. The test made at the CEV included impacts of masses up to 800 Lb. on EDM piles, with impact speeds around to 5 m/s. The number of EDM layers in the pile allowed to compare different strain rates. The stress vs. strain rate relation seemed to be directly related to the strain rate, although we know that there is a more complex internal dynamic or the air leakage than a mere strain rate dependance. A choice had to be made between the long development of a user law including an "imprisoned air" variable and leakage law, or the direct use of MAT_26 as it is. Our decision was to first use the available formulation for global validation of the model, and go further in physical modelling later if necessary. Eventually the direct relation between stress amplification and strain rate given by the LCSR curve in MAT_26 proved to be largely enough for our purpose, since the honeycomb crushing in airdrop applications always happens in one run, is monotonous, and seems to be such that the air leakage happens in a nearly steady-state equilibrium between internal pressure, strain rate and viscous effects.

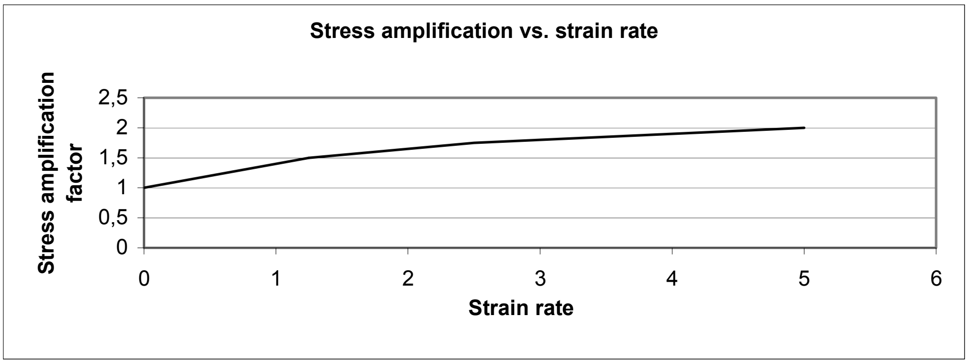

Fig. 4 : Shape of the LCSR input used in MAT_26 for the strain rate dependence of the EDM resistance.

The second statement of the test team was the impossibility to measure the off – axis behaviour with the available testing machines. The modelling team decided then to compare various results available for other honeycomb materials, analyse whether the actual off – axis behaviour had any real importance for airdrop applications, and also conducted a few desk-corner experiments to get rough but valuable data.
The results showed that the orthogonal stiffness and resistance is usually 1/7 to 1/10 of the in axis values for honeycomb materials, and manual torsion experiments allowed to measure approximately the shear module of 1.5 GPa.
Another noticeable fact is that the EDM doesn't take that much shear stress during airdrop, since the load's riggings takes most of it, and the horizontal load velocity leads to a rolling movement at ground impact more than EDM shear strain. Thus, the EDM honeycomb works in - axis in most cases.

Experimental Investigations

1. Model validation :

The CEV's airdrop team had test results available for the flat impact of the ERYX missile load (fig 2.) that we compared to simulation results as a validation case.

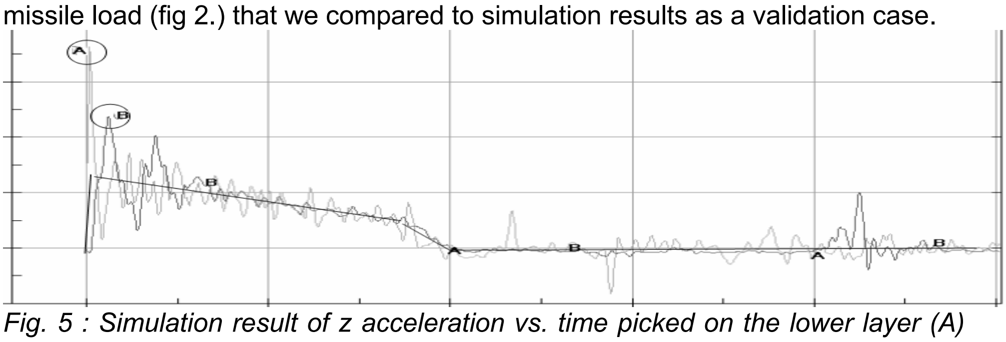

Fig. 5 : Simulation result of z acceleration vs. time picked on the lower layer (A) and higher layer (B) of the load, with a polyline outlining the basic deceleration shape : oscillations around a decreasing value (related to the strain rate effect).

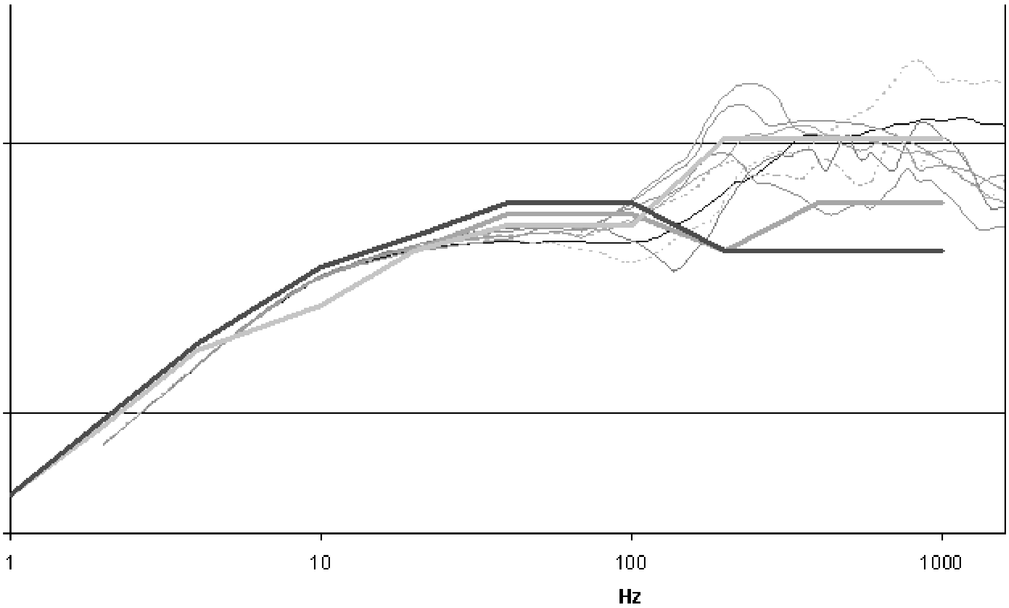

Fig. 6 : z-axis SRS computed with experimental acceleration results (thick) and simulation results (thin lines) on various stations of the ERYX load for a flat impact. There seems to be an average offset of about 1DB between test and simulation in the 1-100 Hz range, that remains inside the manufacturing tolerances of the EDM and sink rate tolerance for the test case. The SRS is not flat but slightly growing in the 10-100 Hz area ; this is proved to be related to the strain rate effect in the EDM.

The simulation result for a flat impact is close enough to the experimental result in this case.

The second experimental result available comes from actual airdrop tests on a 4WD vehicle that impacted the ground tail first.

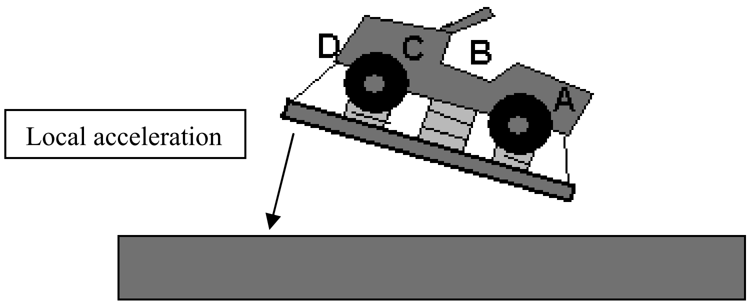

Fig. 7 : Illustration of the 4WD vehicle impact with acceleration measurement locations A (ammo stock) B (seat) and C (engine), and the locations for simulation result analysis (A, B, C and D).

The impact on the A side causes a rotational acceleration of the load we call the “whiplash” effect. The conservation of momentum leads to a local acceleration on the C side before it impacts the ground. The effect is obvious on the measured accelerations. Moreover the experimental results shows that the deceleration on the C location happens after the A side has already stopped, and is a little higher than on the A side because of the locally increased impact velocity and EDM strain rate effect. The measured deceleration on B station longs twice longer than on A and C stations and is approximately twice lower.

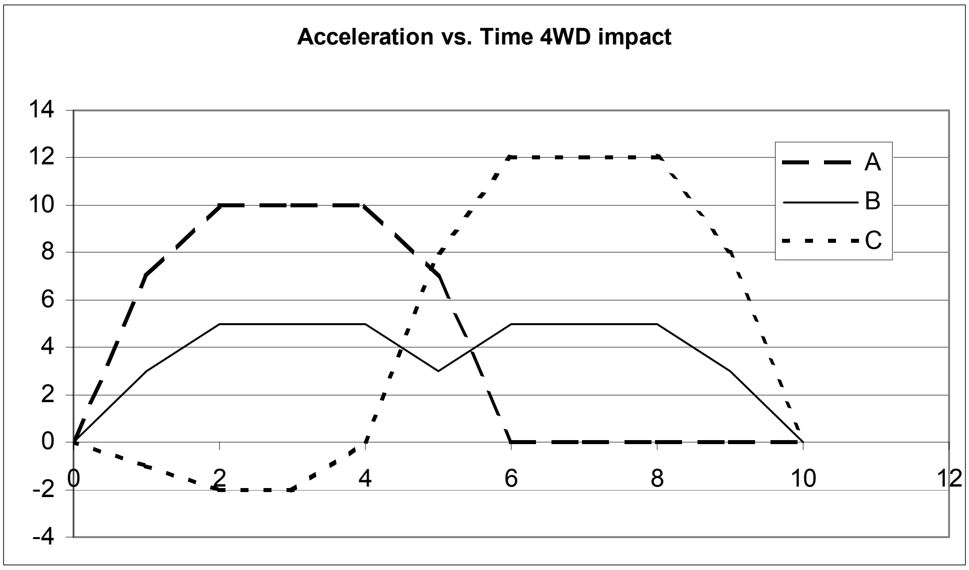

Fig. 8 : Test results : schematic illustration of the measured z axis acceleration on stations ,A B and C of fig. 7. The actual data is restricted.

The same case has been simulated with a rigid vehicle in LS-DYNA. The simulation results exhibit the same separation in time of the shocks on A and C locations, and the lower shock level on B location. Fig. 9 shows that the SRS calculated with the simulation result is in scale with the acceleration measured during the flight test.

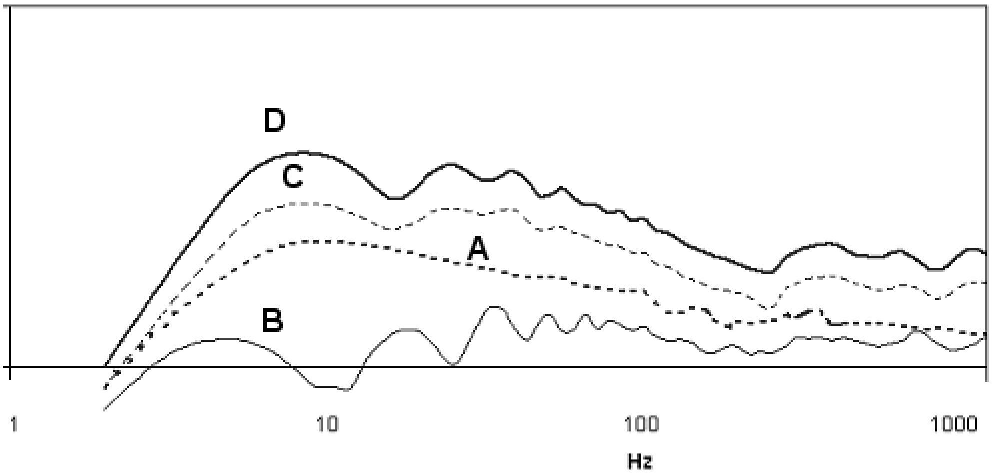

Fig. 9 : z-axis SRS calculated with simulation results for the A, B, C and D locations of figure 7. A and C are about twice tougher than B, C being the toughest.

2. Extrapolation :

The model having proved to be accurate for the aforementioned cases, it has been used to analyze the whiplash effect on the ERYX load (fig. 2) that has never been observed in tests.

The load geometry is rotated so that a platform corner impacts the ground first.

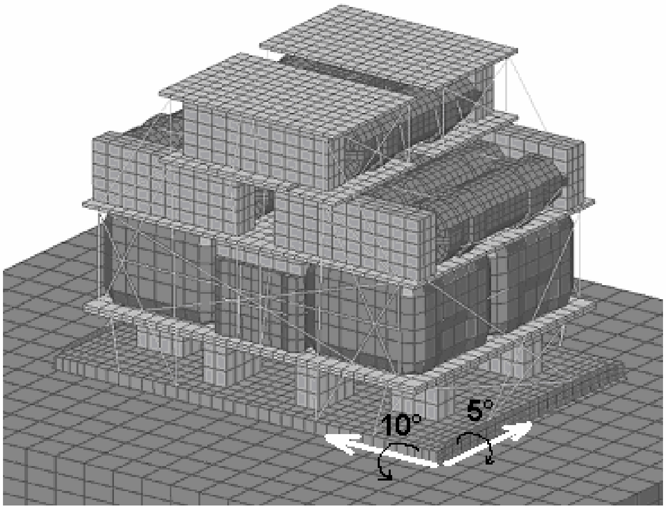

Fig. 10 : Rotations applied to the ERYX load mesh, so that the origin corner impacts first.

The resulting impact shows the same whiplash effect as in the vehicle case, with an extra event that could not have been observed on a vehicle : During the first moments of the impact, the load's layers separate on the last impacting side, because of the progressive propagation of the whiplash movement in the assembly. The platform accelerates first, then the movement is transmitted to the first layer by the rigging ropes, and so on. This causes the box on the last impacting corner of the load to hit the EDM with its only inertia instead of the inertia of the whole load, and a moment later to be impacted by the rest of the load. Contrarily to a vehicle that behaves approximately like a solid and nearly rigid body, a stacking of boxes can suffer the aggravating effect internal collisions and isolated masses.

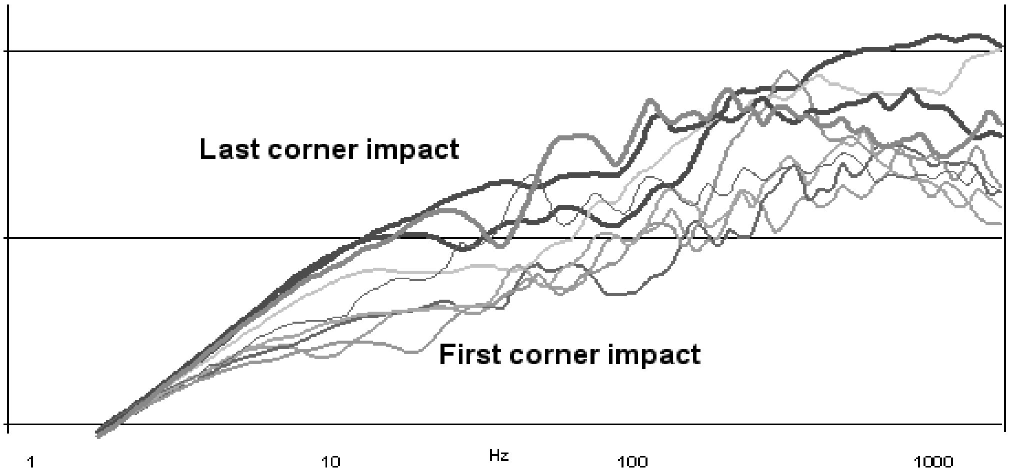

Fig. 11 :z axis SRS – simulation result for the corner impact of the ERYX load

This result actually gave a new orientation to the CEV's airdrop team's work on ERYX in 2005, by giving figures that were not available from test records due to insufficient test facilities or funding.

Summary and Conclusions

A pragmatic approach for modeling the strain rate effect in honeycomb paper EDM and a simplistic modeling of loads with rigid bodies and elastic material was proved to be accurate enough to predicts shocks at ground impact for airdrop applications. These models allow to analyze the parametric effect of velocities, angles, EDM geometry, in cases that could not be exhaustively tested because of the delay and cost.

The CEV airdrop team has a project for defining a qualifying impact case for ammunition airdrop in 2005. It has been decided that all their analysis will be based on LS-DYNA simulation, physical tests being only used as validation cases and in a restricted number.