SIMULATION OF THE IMPACT ON GROUND OF AIRDROP LOADS TO DEFINE A STANDARD WORST CASE TEST.

AUTHORS:

Yves de Lassat de Pressigny
Thierry Baylot
Centre d'Essais en Vol, DGA, Ministère de la Défense, France

CORRESPONDENCE:

Yves de Lassat de Pressigny
Centre d'Essais en Vol
Phone +33 5 61 31 39 06
Email Yves.de-lassat@dga.defense.gouv.fr

ABSTRACT:

The French Flight Test Centre in Toulouse (CEV Tl) made in 2004 prototype simulations of ground impact after airdrop (2d-40, 5th European LS-DYNA users conferences.) Its purpose was to enable the test centre to achieve parametric analyses of the shock level produced by airdrop with a combination of simulation and real tests, which was not feasible with tests only (because of the number of test cases required). Indeed a first proposal with several hundreds test cases had been rejected by the French Army Headquarters because of its high cost and length.

An alternate solution with about a hundred simulation results and fifty four life tests was finally accepted and realised throughout 2005 and 2006. LS-DYNA was used to demonstrate what were the cargo fitting techniques and impact conditions that could produce the highest shock levels with the current state of airdrop technology. This gave the experts early hints in their purpose to design a standard test case to assess weapon systems reliability after airdrop. The testing campaign afterwards was focused on checking key points of the simulation analysis and evaluate the importance of non deterministic effects that could not be simulated, which is needed to estimate the actual value of the future standard qualification test for airdrop.

KEYWORDS:

Impact, Airdrop, honeycomb, shock

INTRODUCTION

Le Centre d'Essais en Vol (CEV, flight test centre, part of the French armament procurement agency DGA/MoD) has expertise in the field of airdrop. One of its tasks is to adapt the airdrop system to ammunition and armaments containers and to measure the shock generated by its impact on the ground for other national specialists to evaluate capability of weapons to operate safely after airdrop. Since the 90', a modelling and simulation team has been developing FEM analysis applications to support expertise. In 2004 simulations on LS-DYNA were proved to be accurate enough to numerically evaluate these shocks[1].

By the same year, the program services of DGA asked for a new experimental mean to generate and measure shocks for airdrop, not based on an adaptation of the airdrop system to the weapons but on a state-of-the-art worst case. Indeed, adaptation helps minimising the shock level on a given weapon or weapons system part, but also makes it characterisation possible late in the procurement process. A state-of-the-art worst case would be defined independently from any specific weapon's characteristics, and thus generic specifications could be derived from it.

The trouble is, up to 10 parameters had to be chosen among 2 to 4 possible values, making a total number of possible test configurations of several thousands. Due to high variability of the shock generated [2], comparing two eligible configurations would require 3 physical tests of each. The lowest estimate to allow an analysis based on tests only was 200 tests, and thousands of hours of work. 400 hours of work with LS-DYNA gave results with sufficient physical explanation and proof to reduce the testing phase to 54 high value-added confirmation cases.

MODELS

The only evolution since 2004 [1] is the use of elastic formulations for the weapon system containers instead of rigid formulations. This led to longer computation times, yet the simulation techniques for the airdrop impact case have become stable enough to allow running the models during lunchtime or at night with few enough bad surprises at post-processing.

The model structure is (see Fig. 1) :

1) 1 PD9 airdrop platform modelled as an elastic material with a flexion stiffness

equivalent to the complex, composite structure.

2) 2 aluminium side beams, modelled as rigid.

3) Energy damper material (EDM) : paper honeycomb, modelled with AMT type 26 or 126 with dynamic behaviour

4) Plywood interface, modelled as elastic (stiffness 4,000 MPa)

5) Ammunition or weapon system containers (test specimen)

6) Dummy plywood containers

7) Straps (polyethylene)

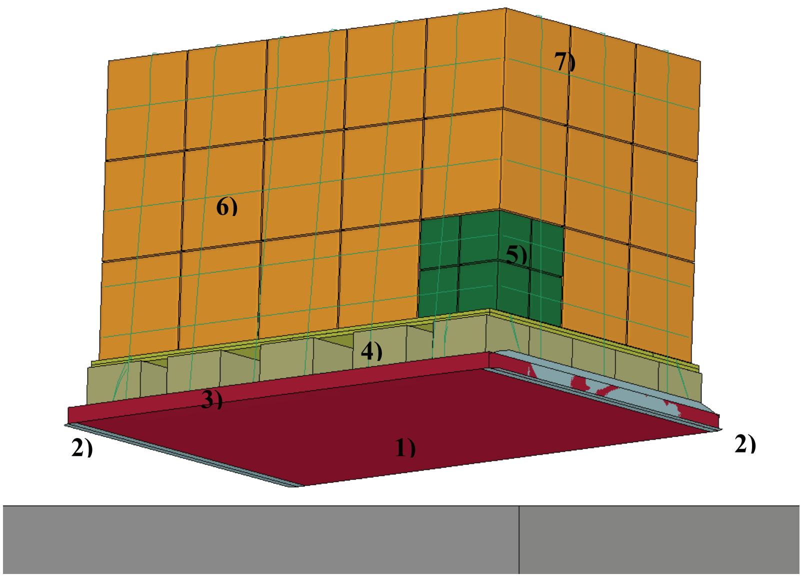

Figure 1 : FEM model of a standard 1 ton airdrop load for testing purpose. Test specimen 5) is surrounded by dummy containers.

The main function of the airdrop platform 1) is to support the military cargo / equipment 5) and 6). Its second function is to roll out of the dropping aircraft in flight, and the side beams provide lateral guidance when engaged in rails lining the plane's hold sides. The side beams also provide holes to tie down the cargo with straps 7).

The cargo containers could not withstand the impact on ground that occurs at vertical speeds up to 9 m/s. An energy dissipating material (EDM) 3) provides the necessary protection to make the process survivable. Since the EDM does not usually use up the platform's surface, a plywood interface is required to fit the cargo containers on the EDM top surface.

PURPOSE OF ANALYSIS

General purpose

The purpose of analysis is to determine and back up with physical explanation what are the cargo fitting options and impact conditions that generate the worst mechanical effects on the tested specimen.

Among the cargo fitting options, the initially most obvious are the relative surface of EDM, the location of the tested specimen (top, bottom, inner, corner …), the size and weight of the dummy containers.

The impact conditions include vertical velocity, impact angle (flat, on an edge, on a corner), horizontal velocity, rotational velocity.

The mechanical constraint generated can be measured with the deceleration curve (best illustrated with a time vs. velocity curve, the associated Shock Response Spectrum (SRS*) and the crushing force applied by the upper containers if the specimen is not on top.

(*SRS : frequency vs. acceleration curve, an ideal transformation of the source shock measured at the base of a system, estimating the extreme acceleration the shock would cause on a simplified 1 DoF oscillator depending on its proper frequency. Used to determine how systems of various oscillatory behaviour can be affected by the shock according to their proper frequencies.)

Experts' input

Various former empirical observations were available to start up the simulation parametric analysis. Results obtained through tests showed out that an impact with angle could cause high SRS levels at high frequencies, when the specimen was placed on the last corner to impact (see Fig.2). CEV also had feed back from another test centre that expressed scepticism when shock levels specified for shock table testing exhibited velocity changes up to 17 m/s to simulate impacts at less than 9 m/s. Another common empirical result was that shock at low velocity (4 to 5 m/s) could cause shock levels higher than an impact at high velocity (9 m/s) on loads of the same design. It was believed that when the kinetic energy is not enough to crush the honeycomb EDM further than its initial elastic deformation limit, the resulting shock was amplified as compared to the expected shock based on the EDM resistance in the permanent deformation range (see Fig. 3).

This knowledge was also compared to the simulation results.

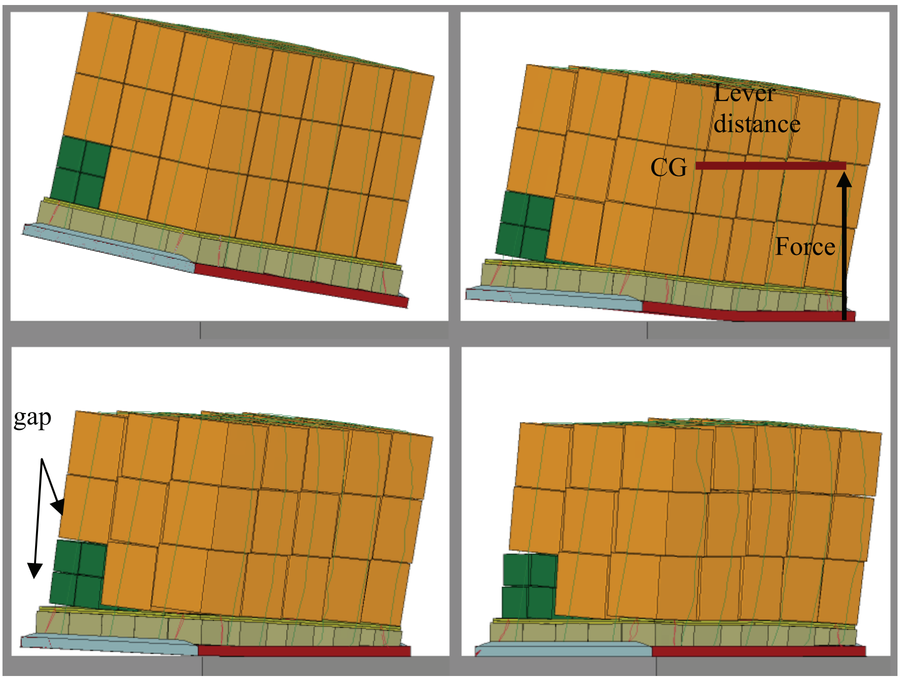

Figure 2 : Kinematics of the loads' impact on ground. The test specimen is placed at the bottom corner that impacts the ground last.

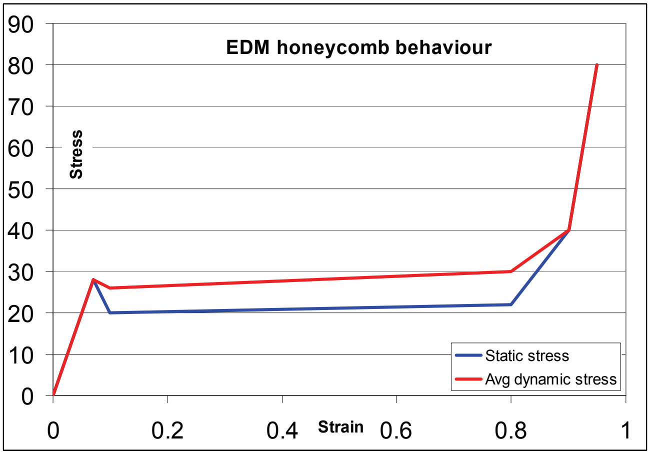

Figure 3 : Mechanical reaction of the honeycomb EDM to axial compression, in static conditions and in dynamic conditions representative of the strain rate encountered in airdrop applications.

SIMULATION RESULTS – SUPPORT TO EXPERTISE

One major advantage of numerical analysis against test is the ability to replay and "measure" at will. Physical testing is limited by the number of cameras and accelerometers that can be set on one test. FEM explicit analysis allows to observe the kinematics of events (thanks to the nodal position or velocity history as well as thanks to the 3D output) and to link them to the mechanical behaviour revealed by the SRS analysis and the contact forces computed on any specified interface. This speeds up the interpretation of results and very often allows to point out the origin of various phenomena when it could probably not have been observed in physical test without a hint to place the sensors as required.

The Whiplash effect

The global result of the numeric analysis show that the worst case occurs when the specimen is located at the bottom corner of the load that impacts the ground last (see Fig. 2), when the load impacts with an angle. Such a situation is common with airdrop at low altitudes and turbulent wind, because the parachutes' oscillations are often not damped fast enough.

Whiplash effect – local velocity increase

When the load first hits the ground (first corner impacts), the momentum generated at CG causes the load to rotate until the last corner impacts ; this rotation causes a local increase of the vertical velocity that can have a significant effect on the shock generated (see Fig. 4 marker *1). This phenomenon is enhanced by the state of the art in France, with the use of stiff airdrop platforms that maximise the lever (see Fig. 2 top right) and momentum caused by the force generated on the 1st corner. The aforementioned local impact velocity of 17 m/s for an initial global velocity of 9 m/s was reproduced by the numeric simulation.

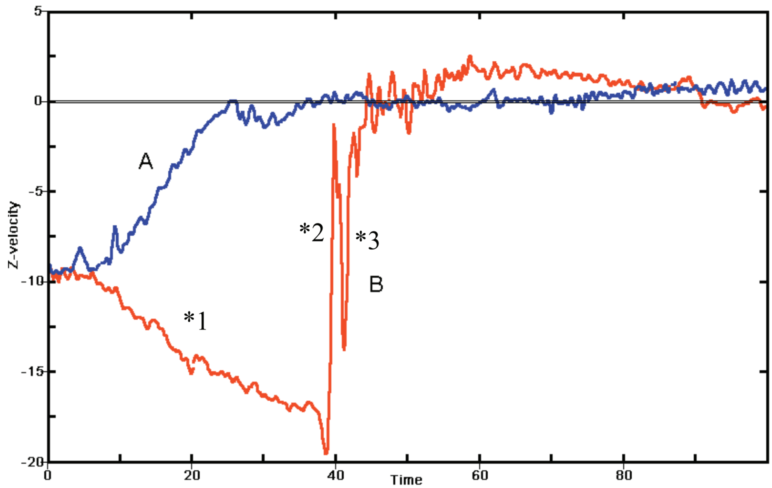

Figure 4 : Vertical velocity vs. time at the first impacting corner (A curve) and the last impacting corner (B curve).

Whiplash effect – SRS increase at medium frequencies

This phenomenon causes the worst effect in the intermediate frequency range of the SRS (see Fig. 5 marker *1). This implies that most military equipment placed in the "last corner" will suffer the actual effects of a 17 m/s impact when the initial velocity was only 9 m/s.

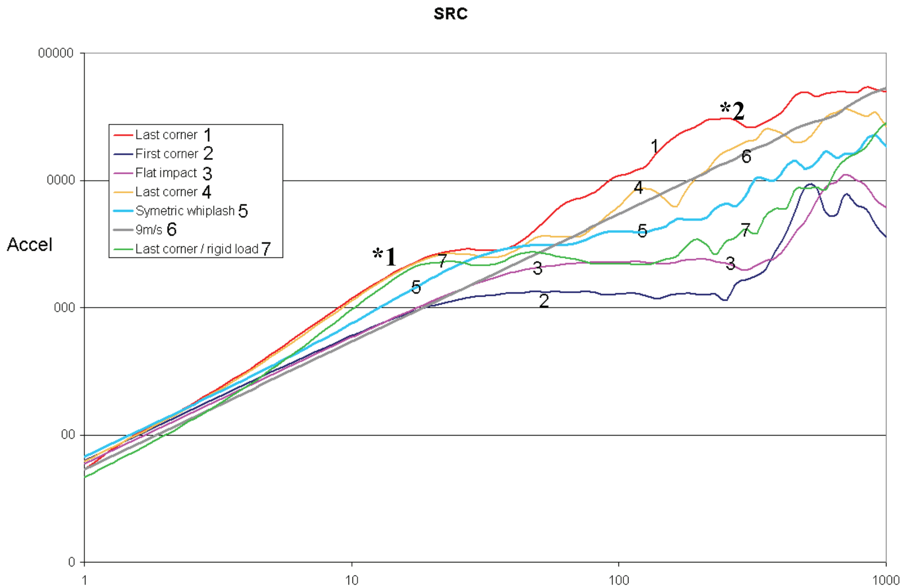

Figure 5 : Shock response spectra for various locations of the test specimen and various impact conditions. Marker *1 shows the area affected by the whiplash effect. Marker *2 shows the area affected by the violent local impacts in the last impacting corner.

Local impact effect

Another phenomenon causing higher shock levels on the last corner is the loss of contact between the load's layers during the initial rotation. When the load impacts with an angle, the plat form rotates first and the containers follow when the rigging belts tense. Gaps appear between the containers(see Fig. 2 bottom left), leading to two consequences:

The bottom box in the last impacting corner impacts the plywood interface with no contact with the upper boxes. It works then with the full resisting force designed for the whole load and only its own inertia, which causes a deceleration much harder than in a flat impact case (see Fig 4 marker *2). The eventual re-contact of the upper containers then causes an additional downward acceleration (see Fig 4 marker *3) and generates pressure forces on the specimen much higher than in a flat impact case, when there is no loss of contact prior to deceleration.

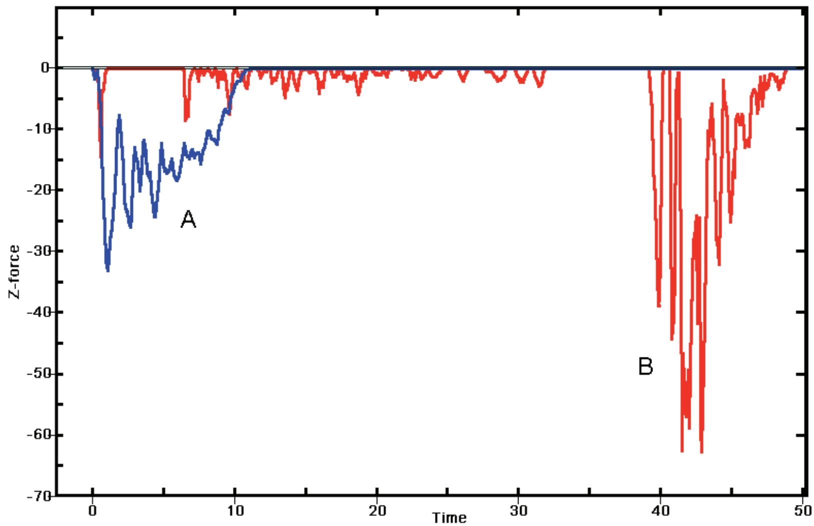

Figure 6 : Z force applied on the top of a specimen placed in a bottom corner, in case of a flat impact on ground (A curve) and in case of an impact with an angle (specimen in the "last corner", B curve).

SIMULATION RESULTS – SUPPORT TO TEST INSTRUMENTATION

Aside from reducing the number of configuration to test, the simulation support also gave critical information what to measure during the physical tests to make them successful.

The shock being supposed worst in the last impacting corner, simulation was for a part focused on mapping the area where the aggravation was significant. This allowed specify the number and location of accelerometers needed to confirm this phenomenon and the exact portion of the area it affects .The simulation results also re-directed the instrumentation team to a higher class of accelerometers, the numeric results showing that the extreme acceleration to be measured would be up to 4 times the range of the sensors initially planned to be used.

Eventually, the 3D LS-DYNA output helped placing the cameras so as to observe the local behaviour of the last impacting corner, and get proof of the loss of contact exhibited in simulation.

Figure 7 : 1 centimetre gap captured on video !

Physical and optical instrumentation being set so as to catch all the phenomena observed in the numeric analysis, the life testing phase gave 100 % high value added results. Thus all tests conducted directly helped to prove the worst (yet representative) impact conditions had been found, by proving the physical phenomena found through simulation actually happened.

SUMMARY AND CONCLUSIONS

Simulations prototyped in year 2004 led to a huge improvement of the expertise and testing capability in CEV the very next year. A basic level use of FEM analysis with a strong mastery of the purpose and limits of the modelling hypotheses was the key for success : all of the phenomena observed could be proved to be physical and general or artefacts, thanks to the simplicity of the models that allowed to understand and analyse every result with common mechanics knowledge.

REFERENCES

1. "Numerical simulation of ground impact after airdrop", 2d-40, 5th LS Dyna users conferences, May 2005