STUDY OF THE EFFECTS OF A PARTICULAR FUEL TANK FILLER IN CRASH ENVIRONMENT

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ABSTRACT

Data from a previous experimental work, carried out by the authors in the crash test laboratory of the Aerospace Department of the Politecnico di Milano, has been used to validate a numerical model of a fuel tank filled with water and with a particular aluminum filler. In that work several crash tests had been performed to analyse the behaviour of helicopter fuel tanks when filled with water and expanded aluminium foils. Accelerations and pressures had been measured to compare the behaviour of the tanks with and without this particular filler. Results of the previous work showed how the expanded aluminium foils (already known to be efficient passive explosion suppression media for aeroplanes fuel tanks) greatly reduce the leakage of the fluid in case of impact and subsequent failure of the tanks; a reduction of the pressure increment, caused by the movement of the fluid towards the impact area, has been noticed too. Besides these data, new experimental tests have been carried out to characterize the filler and its interaction with the fluid and the fuel tank. A porous model has been chosen to simulate this particular filler. Simulation of impact and leakage tests have been carried out showing the great capability of such a complete model to simulate different impact scenarios and to study the dynamics of both the fuel tanks and the filler when subjected to high decelerations or crashes.

1. INTRODUCTION

Fuel tank explosion resulting from ignition of vapours by various means is a major cause of aircraft loss. Over the years, many concepts which seek to prevent or suppress such explosions have been explored. Among these a particular expanded aluminium foil has been investigated for several years by a performance and qualification test program to meet the Military Standard MIL-B-87162A (USAF).

The purpose of the present research is to carry on the study of the effect of the filler on the fuel tank in case of a crash event started in a previous work (see ref. [1]). Failure of the tank or leakage of the fuel resulting in explosion of an aircraft would vanish the great efforts that have been made, in recent years, in the design of more crashworthy aircraft systems, with an eye to reduction of fatalities and serious injuries in survivable accidents.

2. EXPERIMENTAL RESULTS

In the previous work tests were carried out using a *deceleration sled facility* of the Aerospace Department of the Politecnico di Milano. Several fuel tanks were driven against a rigid wall at the end of a test sled run. To perform the tests two wooden plates were mounted, one on the sled and one at the anvil impact area. Fuel tanks were put on the sled wooden plate, and left free to move forward during the sled braking phase (see figure 1). When the sled was at its final stop position the distance between the two plates was less than 1 cm, allowing a soft sliding of the tank from the first to the second plate. Two L shaped profiles were installed on both the plates to maintain the direction of the tank motion within a small angle. Acceleration and pressures were measured during the tests.

Figures 2 and 3 show the comparison of the accelerations curves of the fuel tank and the pressures curves of the water measured during two of the several tests carried out with and without the filler. Comparison of accelerations as well as pressure time histories clearly shows how the presence of the filler help reducing peaks and loads on the structure. After the test residual deformations of tanks were measured by means of a laser distance transducer at different locations of the upper, lower and rear surface. Comparison of the deformed configuration (figs. 4, 5 and 6) shows that the tank with the filler has a lower final plastic deformation.

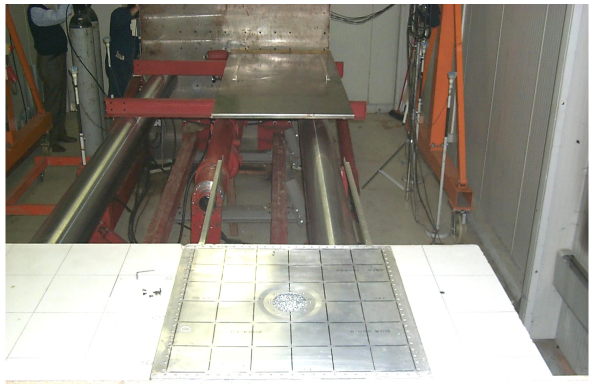


Fig. 1 - Test equipment: global view.

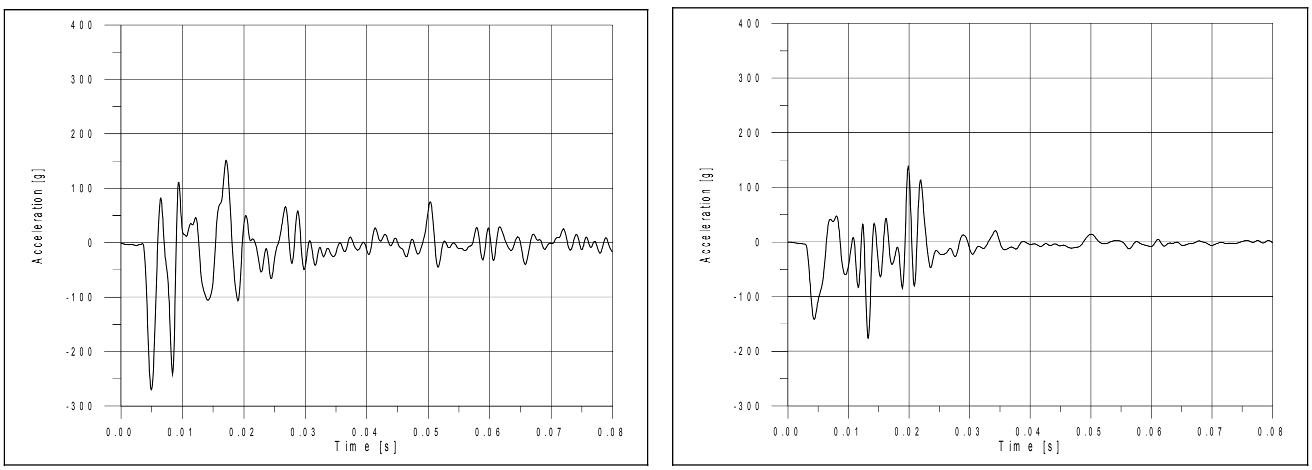


Fig. 2 Forward acceleration with (right) and without (left) the filler

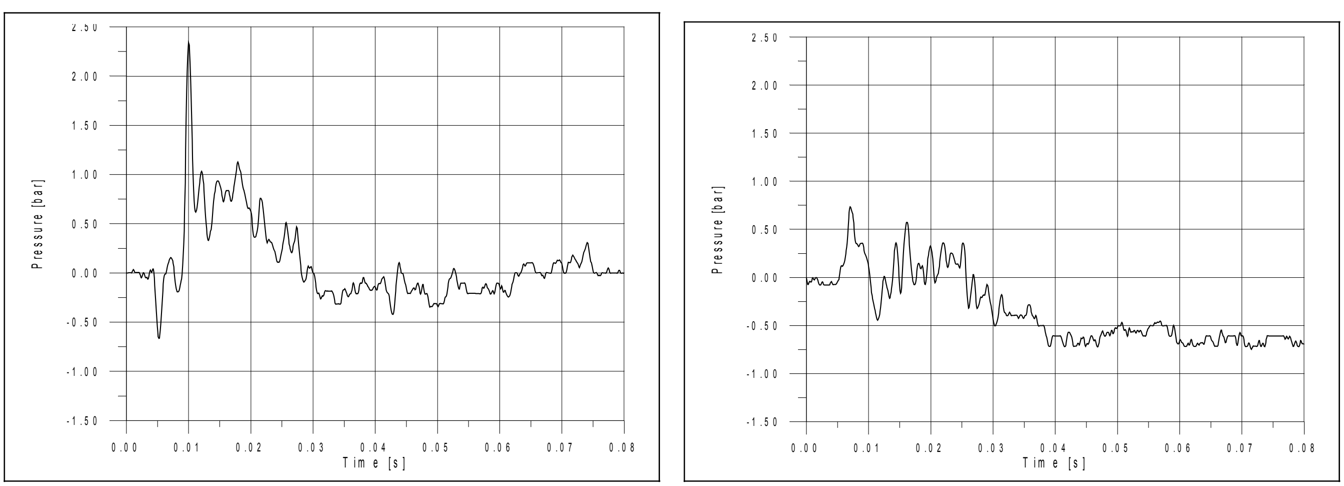


Fig. 3 Side pressure with (right) and without (left) the filler

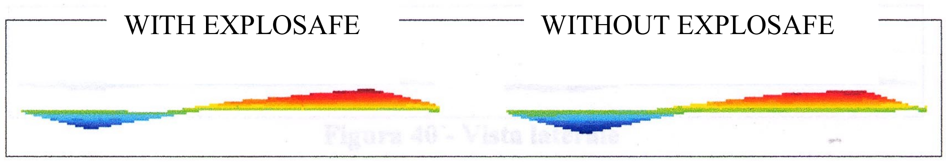


Fig. 4 – Upper surface final configuration, axonometric and lateral view.

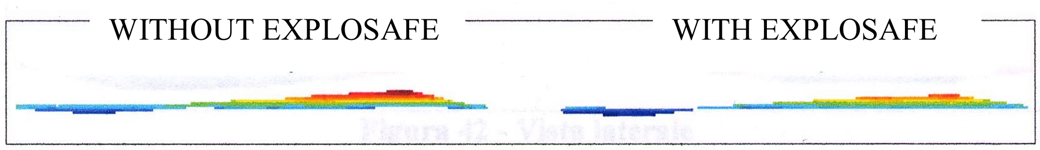


Fig. 5 – Lower surface final configuration, axonometric and lateral view.

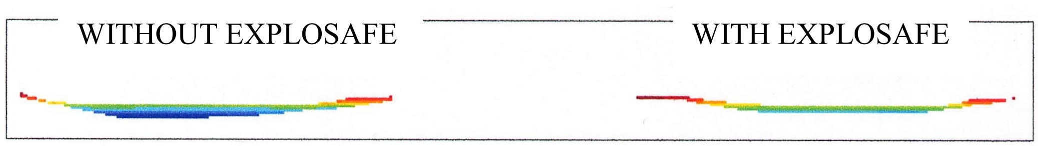


Fig. 6 – Rear surface final configuration, axonometric and lateral view.

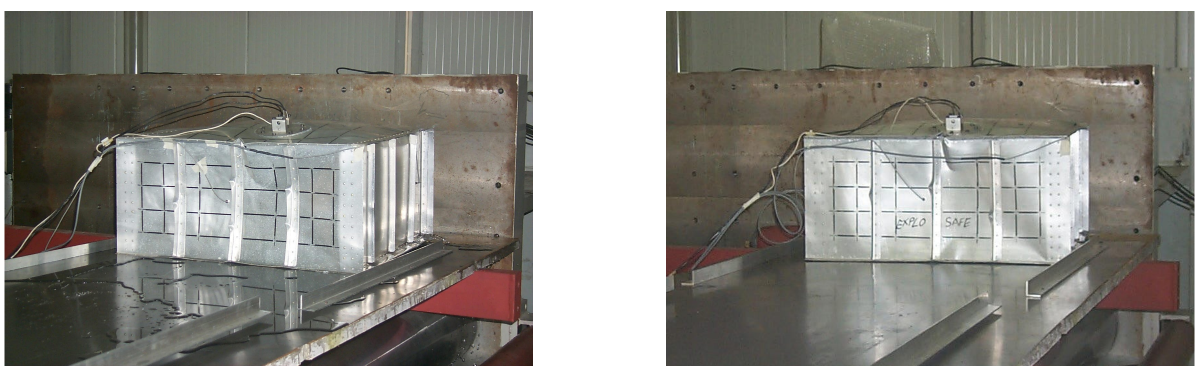


Fig. 7 - Rear view of the items after the tests with (right) and without (left) the filler.

3. NUMERICAL SIMULATIONS OF THE FUEL TANK

Experimental pressure time histories and final deformations were compared with results obtained with an explicit FEM simulation of the impact. To this end, a FEM model of the tank, of the horizontal wooden plate and of the water was made. The impact simulation was performed with the DYTRAN code. Experimental initial impact condition, obtained from analysis of high speed camera films, were imposed. Comparison of the final deformed configuration shows good agreement between experimental and numerical results. Comparison of pressure time histories on the tank rear shows a good initial agreement, in particular for the 0 bar absolute pressure cut-off, but shows also a quick loss of correlation between experimental and numerical data .

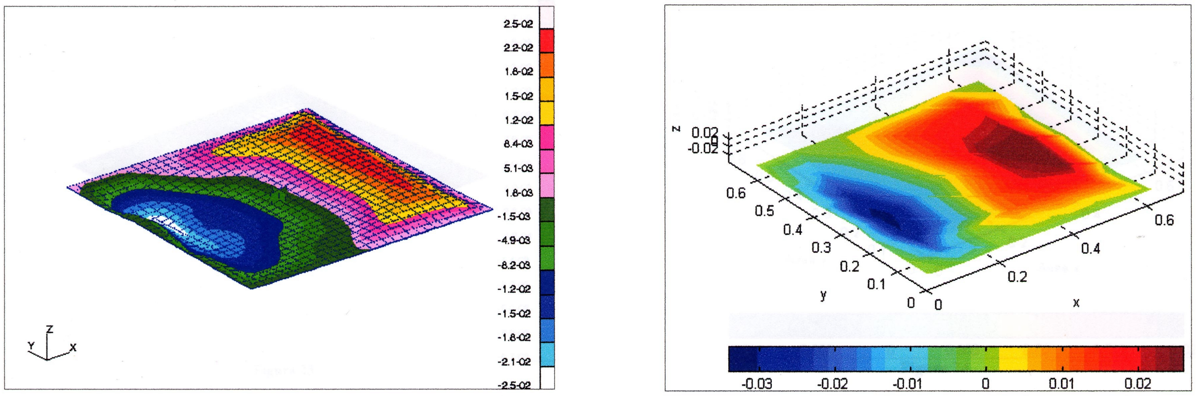


Fig. 8 – Numerical (left) and experimental (right) upper surface final deformation.

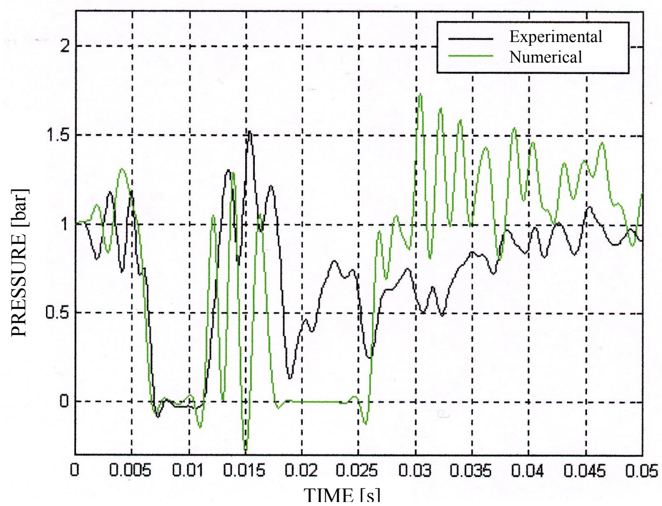
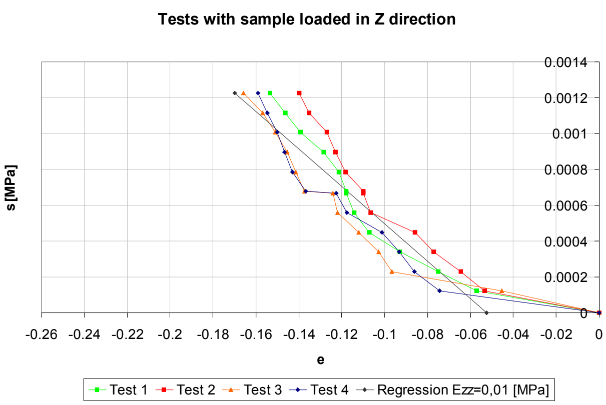


Fig. 9 – Numerical and experimental absolute pressure time histories.

4. NUMERICAL SIMULATIONS OF THE FUEL TANK WITH THE FILLER

The next step, and object of this paper, was to try to simulate numerically the structural behaviour of the filler combined with its internal flows, regardless of thermal and chemical phenomena. Attention was focused on the available mathematical models able to describe them. Typical applications are studies of soil consolidation for foundation problems, analyses of soil settlement in well drilling operations, examinations of blood diffusion inside cerebral tissues in case of aneurysm, investigations of the propagation of organic liquids inside other human body tissue (bones, muscles, etc.) and any other general filtering problem. The starting point was found in M. A. Biot's theory for partially or fully saturated terrain [2]. Unfortunately Biot's model even if quite general, deals with low frequency phenomena, thus inertial loads can not be considered and pore fluid speeds has to be rather slow. For this reason two different kind of simulations were carried out to understand if this approach would led to some good result also in the simulation of the filler in a crash environment where high frequencies are typically present. The first was the simulation of the impact of a fuel tank totally filled with water, with and without the filler, against a rigid wall. The second was the simulation of a forced leakage from the same tank, in which a hole had been opened. Both the simulations were performed with a static analysis with the ABAQUS/Standard code which better suits to the simulation of interaction between fluid and porous media. In

the first model, ribs of the front face of the tank subjected to impact are initially loaded with nodal forces opposite to the direction of motion. Their value, equal to zero for few milliseconds to let the whole structure and fluid settle under gravity, increases rapidly until yielding is achieved, then returns to zero. In the meantime, while nodal forces decrease, the entire collision surface is subjected in the same direction to an increasing pressure. Its value reaches the maximum when nodal forces come to zero and last for about one millisecond before returning to zero. In the second model there was no properly defined load system, since an outflow speed is imposed to water from the faces of solid elements adjacent to the hole. Likewise nodal forces, outflow velocity is put equal to zero for few milliseconds in order to let the system stabilise, then is brought and maintained to a value of 5 [m/s], as measured from the tests.
A compression test was carried out to determine the nine independent terms of the filler orthotropic stiffness matrix and a permeability test was carried out to determine, as a function of void ratio, the six independent terms of the filler orthotropic permeability matrix. All the tests were carried out at the Aerospace Engineering Department. Date from the tests was used to characterise the filler numerical model.



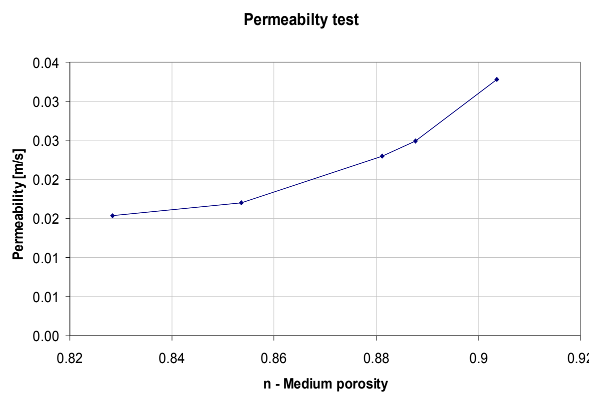


Fig. 10 – Compression and permeability tests.

n_{xy}	n_{xz}	n_{yz}	G_{xy} [N/m^2]	G_{yz} [N/m^2]	G_{xz} [N/m^2]
0,001	0,001	0,001	6850	12500	5000

Fig. 11 – Mechanical characteristics of the filler.

The following figures show the results of the simulations.

Impact model results

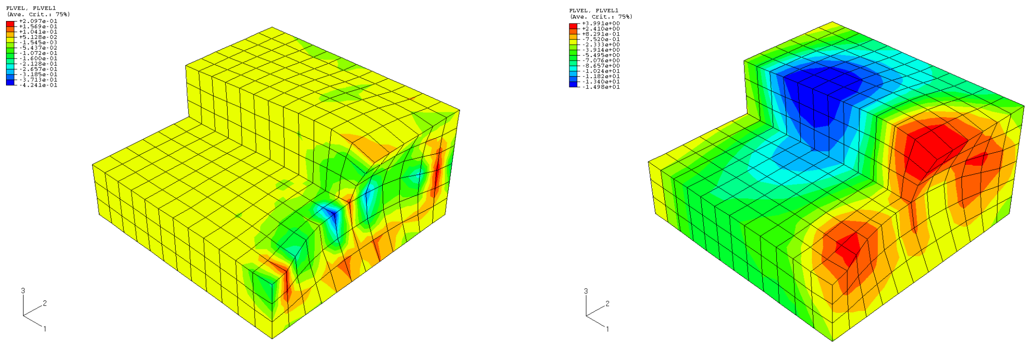


Fig. 12 - Fluid velocity in X direction during impact with (left) and without (right) the filler.

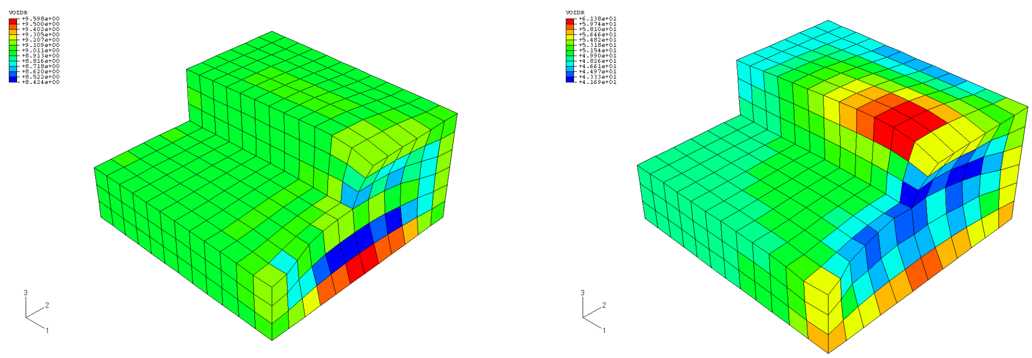


Fig. 13 - Section showing void ratio during impact with (left) and without (right) the filler.

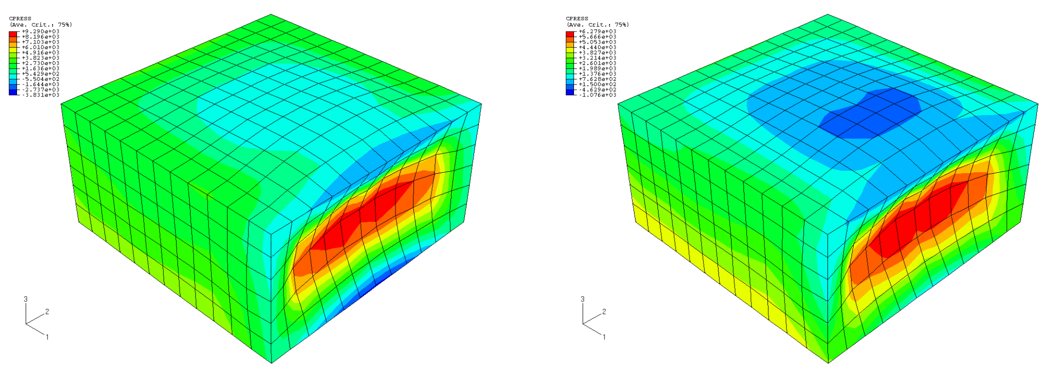


Fig. 14 - Contact pressure between tank and water with (left) and without (right) the filler.

Leakage model results

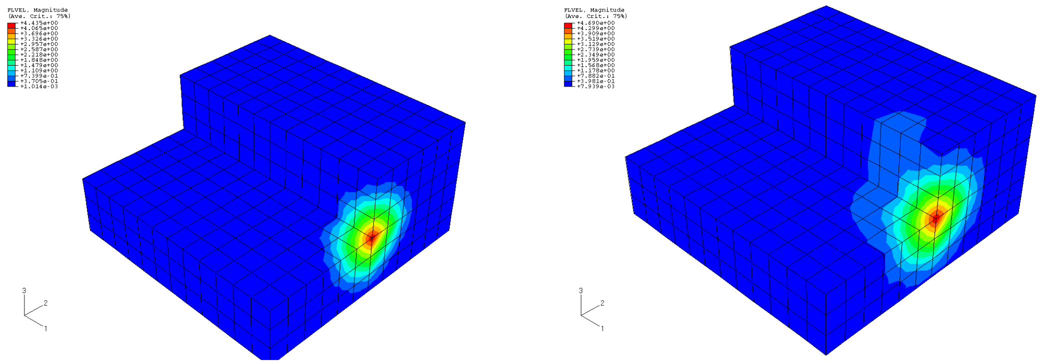


Fig. 15 - Fluid velocity with (left) and without (right) the filler.

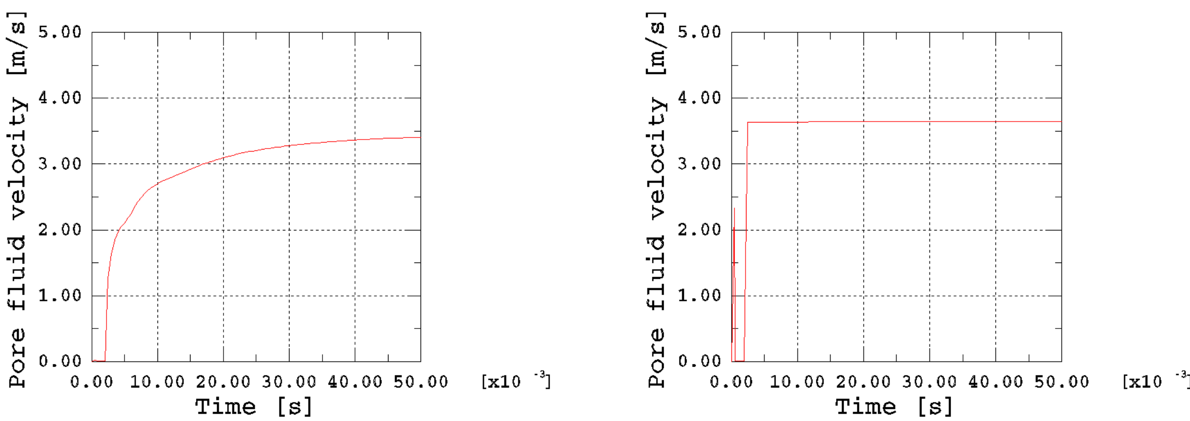


Fig. 16 - Fluid velocity near the hole with (left) and without (right) the filler.

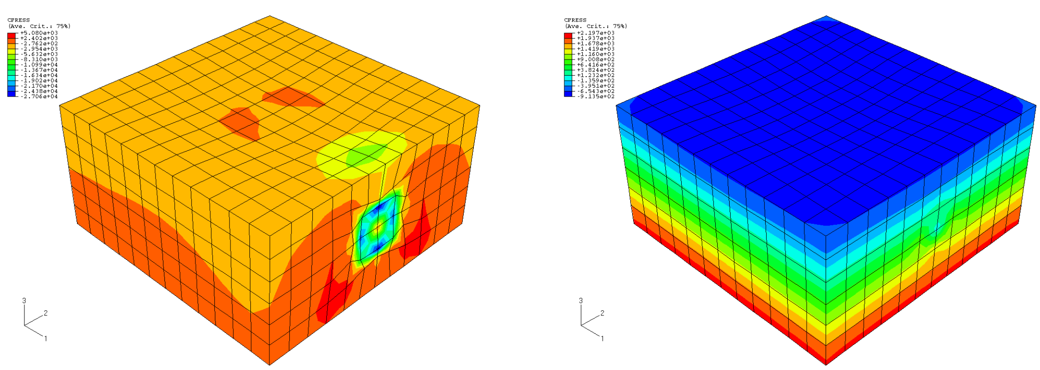


Fig. 17 - Contact pressure between tank and water with (left) and without (right) the filler.

5. CONCLUSIONS

A complete numerical model of an helicopter fuel tank-expanded aluminium foils filler-water has been presented. Simulations reproduce in a physically reasonable way all the phenomena involved. In particular, the mode of deformation of the tank appears correct in the impact models, followed by fluid motion and pressure. The leakage model shows the effects of a fluid suction, highlighting how this determines a contraction of the tank and a constant decrease in liquid pressure. When the filler is present the movement of the fluid appears restricted producing local pressure peaks that propagate through the medium with velocities that are lower than without the filler. Results are quantitatively pretty well confirmed by crash tests performed in the previous work, although the lack of inertial forces strongly influences the dynamic of the system. As a matter of fact, we can see that a certain pressure in water corresponds to an assigned load, but pressure waves aren't modelled and the whole system acts as an overdamped one. The work shows the practicability of the numerical study of expanded metal products and lays emphasis on the deficiencies currently present in calculus codes. It may be the starting point for the development of more adequate numerical systems, in association to the necessity to use solution strategies that can operate with very different material models coupled by complex interactions. The development of a complete model will than be used to better analyse tanks behaviour in different impact scenarios.

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