STRUCTURAL LOADING OF A COMPLETE AIRCRAFT UNDER REALISTIC CRASH CONDITIONS: GENERATION OF A LOAD DATABASE FOR PASSENGER SAFETY AND INNOVATIVE DESIGN

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Abstract

The presented work has been done within EU CRAHVI G4RD-CT-2000-00395 programme, with the support of the European Community. Differently to the previous EU "crash" programmes dealing with aircraft safety, the current one is more dedicated to high horizontal velocity problems. Another specificity of the programme is that it is concerned with problems such as bird, debris or ground obstacles impacts, and crash on rigid or soft soils.

The proposed paper presents hard landing simulations of large aeronautical structures using explicit F.E. codes, such as RADIOSS. The main technical difficulties arise from the dimensions and the complexity of the structures to be modelled on the one hand, and from the complexity of the very local ruin phenomena (rupture of material or failure of riveted joints) on the other hand. When we study aircraft behaviour, it becomes necessary to consider different configurations (nature and stiffness of the impacted surface). The other aim of the project is to improve confidence and assess representativness of models for ditching simulations.

In a first part the document describes some drop tests simulations confronted to experimental results.

This comparison enables one to validate the selected numerical approach (complete structure, rivets models and behaviour laws) before introducing refined meshes (two non linear areas – rear and front parts) in a complete commercial aircraft F.E. model which is being built up by ONERA and Airbus France.

In the second part of the work, the objective is to run parametric cases (speed and orientation of the aircraft relatively to the impacted surface, for instance) to evaluate the influence on the structural behaviour and loads transferred to the cabin environment and passengers, in case of hard ditching.

The specificity of this study is to determine structural loads of a complete aircraft under realistic crash conditions, and more particularly relatively to the impacted surface stiffness (water) and generate a load database (accelerations, velocities, displacement, forces) for the cabin environment which can be used for the design of innovative cabin safety features with the aim to improve passenger safety. Another interest is to study failure of secondary structure and components inside the cabin with the aim of improving passenger survivability and reduce fatality rates.

1 Structural modelling with E.F

1.1 Numerical modelling of a A321 frames

1.1.1 Introduction

An A321 aircraft model has been built up by ONERA and Airbus France with the aim of running different configurations (hard landing, ditching...). At this point of the study, ONERA is more focused on ditching simulations. Figure 1 shows the refined A321 numerical model for hard landing and ditching simulations. A comparison of the model with the experiment is done. The experiment is a drop test achieved at the CEAT (Aeronautical Experimental Center of Toulouse) during a previous EU programme in which ONERA and AIRBUS were involved.

1.1.2 A321 refined modelling

In a first study [1,2] ONERA performed some ditching simulations with a coarse F.E. model. The aim was to show the feasibility of such a simulation. A complete Airbus A321 model had been built up by ONERA and Airbus France, making the simulation of different crash scenarios possible and realistic enough. However, this model could not represent non local linearities in several highly deformable parts of the structure. To complete this study ONERA chose to refine two areas (rear and front part) of the aircraft to take into account the large deformations in case of crash conditions.
Before the integration of these two refined parts of the aircraft, a first model was built in 1995 to compare it with some purely vertical drop tests. The figure 1 shows the comparison, respectively of the drop test and the simulation for a 6 frames model.

This model was built up by ONERA and qualitatively validated. The methodology is explained in a another ONERA ICAS paper [3].

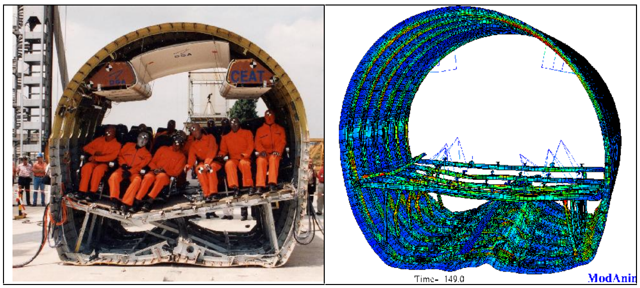


Fig. 1. Comparison experiment-numerical model (Drop test)

The rivets models are developed respectively to laboratory tests (tension and shear tests). For example, in the 6 frames F.E. model 2000 rivets were used.
Owing to the fact that the purpose of these tests is to validate the numerical model, a qualitative comparison can be undertaken.
The level of global deformation is in good agreement with the test result.
This first work was assumed to be satisfactory enough to think about the possibility to apply this refined methodology in larger areas of the A321 existing F.E. coarse model.

1.2 Refined mesh of a complete A321 model

1.2.1 Introduction

At the end of these preliminary works, the DMSE Department decided to go further in the modelling exercise, within the EU CRAHVI project, and complete the evaluation already started, considering the recent developments of the simulation codes. The second challenged difficulty is to deal with a 3D problem including fluid/ structure interactions. The ONERA experience in this study lead to the choice of the new numerical meshless approach : the Smooth Particle Hydrodynamics one [4,5].

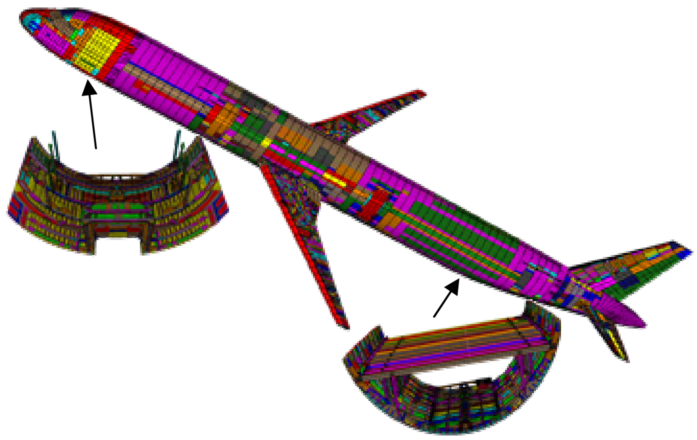


Fig. 2. Complete A321refined model

Figure 2 shows the refined F.E. model used both for hard landing and ditching simulations. This model is able to represent the complete phenomenon when forward velocity is considered.
The front part is refined from frame 18 to 25 and the rear part concerns the area from frame 55 to 64.
These two parts are considered as the more likely damageable areas in the case of severe crash scenarios (first and second impacts).
The final model contains more than 10 000 rivets which have been modelled by non linear spring elements. The complete F.E. model contains:

- 261 904 nodes,
- 2462 brick elements,
- 184 920 shells,
- 10 643 triangles,
- 7120 trusses,
- 23 043 beams,
- 11 120 springs (rivets modelling),
- 868 materials,
- 9839 geometric properties.

1.2.2 Assessment of numerical methods

There are several ways to deal numerically with the problem of fluid/structure interactions. In the present case, an explicit solid code is used.

Some of the solid codes are able to deal with mixed formulations like lagrangian–eulerian (ALE) or SPH/Lagrangian ones, which gives an approximate simulation of certain types of non turbulent flows, around structures slightly deformable, but "at rest" [6].

A comparison between ALE and SPH models has been carried out. The SPH meshless method is of great interest for ditching simulations because there is no numerical stability problems.

2 Ditching

2.1 Ditching simulations

An usual configuration of approach taken by the pilot during ditching situations is the following:

- pitch of plane: 8°
- impact velocity: 60 m/s

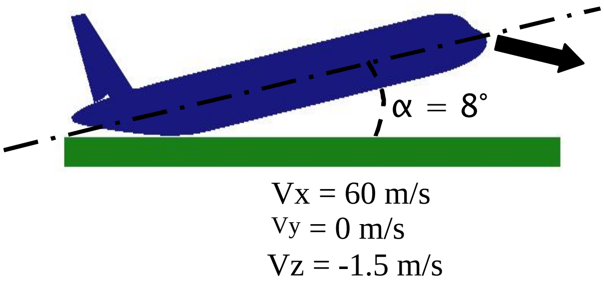


Fig. 3. Ditching configuration

2.1.1 SPH modelling

The SPH modelling is actually a Lagrangian formulation where the observer follows a number of moving particles (part of a fluid or a solid). Indeed in a SPH model, the continuous medium is represented by a finite number of interacting points.
To keep the number of particles constant a constant mass of particle is assumed.

Interactions relations between particles are modelled in order to satisfy the conservation equations. These interactions are solved considering particles which are located within a given limited neighborhood :

$$h = h_0 \left(\frac{\rho_0}{\rho}\right)^{(1/d)} \qquad (1)$$

where h is the smooth length and d the space dimension (1,2 or 3 for lineic, surfacic or volumic space).

So the evolution in time of h is as follows :

$$\frac{dh_i}{dt} = -\frac{1}{d} h \ div \ v_i \qquad (2)$$

with respect to the mass conservation :

$$\frac{dh}{dt} = -\frac{1}{d}\frac{h}{\rho}\frac{d\rho}{dt} \qquad (3)$$

which gives the evolution of h respectively to the density.

In the present case, the use of the SPH approach requires the definition of boundary elements called "outlets", classically used in the ALE models [7,8]. These elements are set in order to absorb the reflected waves at the limits of the model. Thus, they permit to reduce the size of the F.E. mesh.

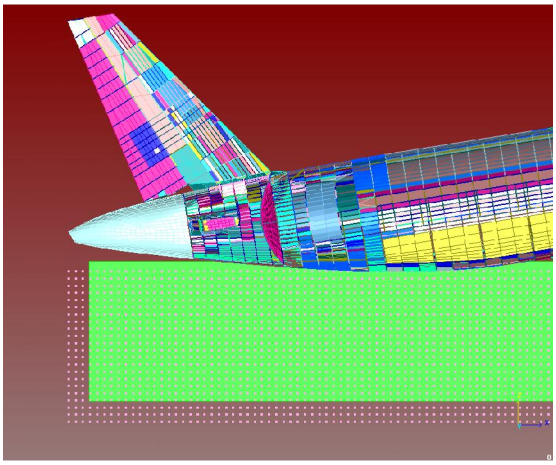


Fig. 4. Outlet particles definition

The particles are distributed along a hexagonal compact net. The mass of the particles m_p relates to the density of the material ρ and the size h_o of the hexagonal compact net, with respect to the following equation:

$$m_p \approx \frac{h_0^{\ 3}}{\sqrt{2}} \rho \qquad (4)$$

since the space can be partitioned into polyhedras surrounding each particle of the net, each one having a volume equal to:

$$V_p = \frac{h_0^{\ 3}}{\sqrt{2}} \qquad (5)$$

This possibility to use “outlets particle” is of a great interest and enables to reduce CPU times.

The following figures present the final configuration of the SPH A321 ditching model. Around 400 000 particles are introduced in this case.

This approach suits to the complete aircraft ditching resolution problem. One can point out that the introduction of air is not taken into account in this study.

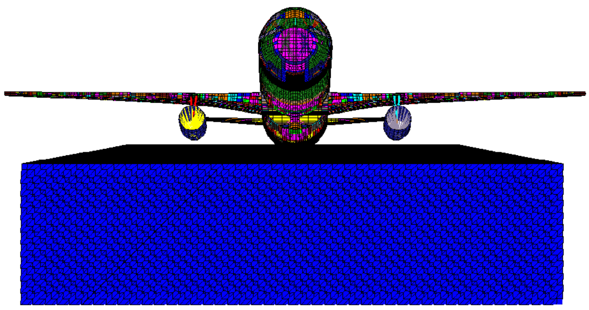


Fig. 5. Final modelling configuration of the ditching simulation

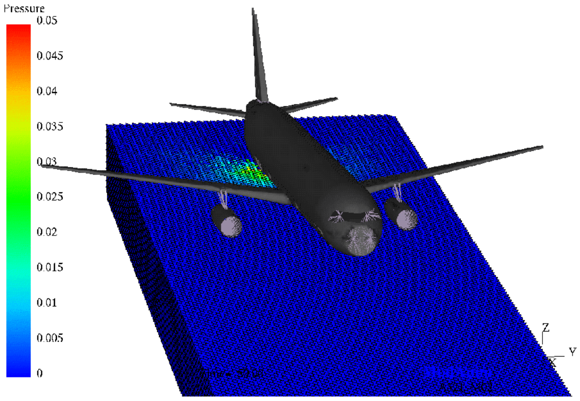
The length of the water mesh used in this ditching model is 90 m. This length is considered to be enough to achieve the complete phenomenon (rear and front impacts). To reduce the size of the model a depth of 5 m has been chosen in which 1 meter (around the water mesh area) is modelled using outlets particles.

2.2 Simulation results

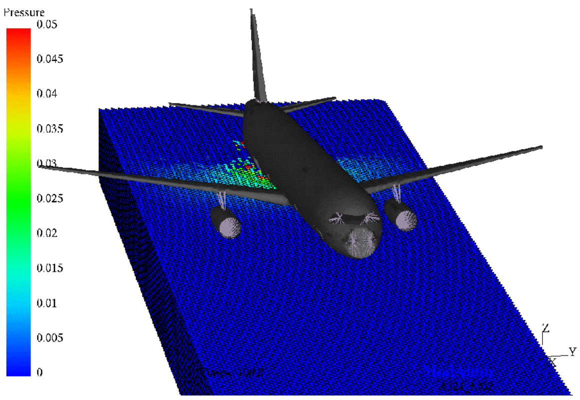
2.2.1 Introduction

The specificity of this study is to determine the structural loads on a complete aircraft in ditching situation. The aim of this work being the qualitative knowledge of the structure deformation, some results are presented respectively to pressure distribution and Von Mises stresses. A special attention is paid to the refined mesh areas.

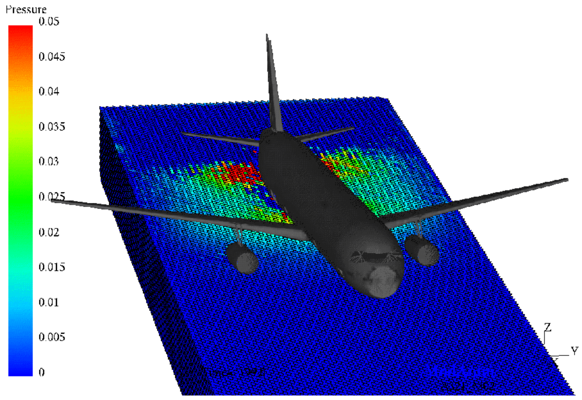
2.2.2 Simulation results



t =50 ms



t =100 ms



t =200 ms

Fig. 6. SPH ditching simulation

The obtained results prove the methodology to be robust enough (through time consuming) to run parametric simulations. A comparison with hard soil is done by Airbus France and ONERA with this refined model.

The advantage of the refined F.E. model of the aircraft is to give access to local non linearities. Indeed the aircraft could possibly be more severely damaged when sea states (wave) or obstacles (hard soil) are considered.

Figures 7,8 and 9 respectively show the Von Mises stresses along the fuselage, the Von Mises stresses and plastic deformations in the aircraft rear part (cargo floor).

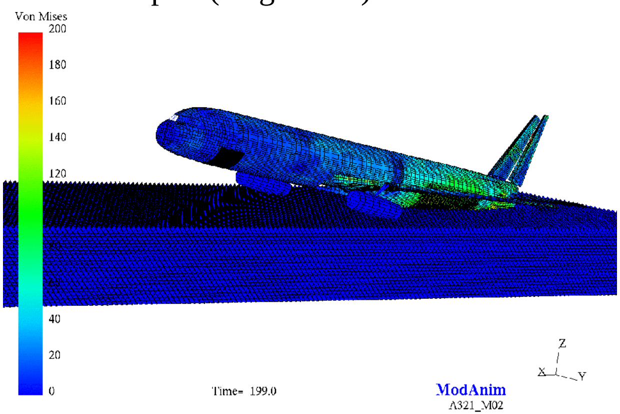


Fig. 7. Von Mises stresses at t=200 ms

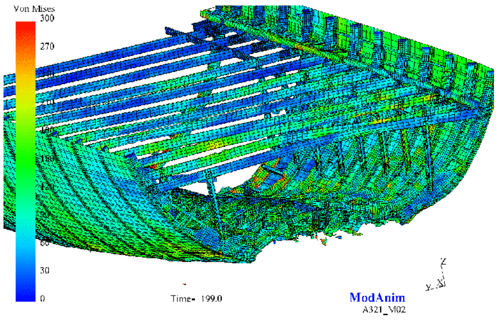


Fig. 8. Von Mises stresses on cargo floor at t=200 ms

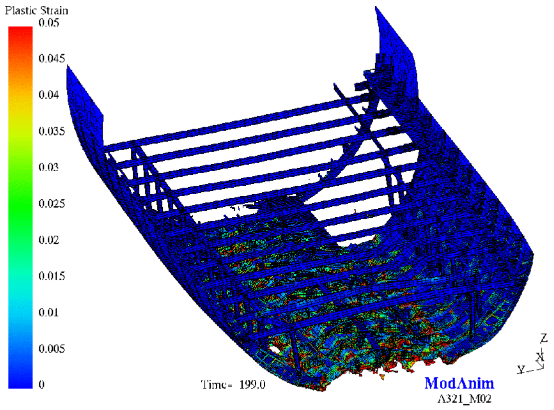


Fig. 9. Plastic strain on cargo floor at t=200 ms

It is really necessary to understand that such a F.E. mesh is based on the AIRBUS CAD model and represents with a good accuracy the real structure. A comparison with vertical drop tests has been done in the past to validate the modelling methodology for hard landing and an extension of the method has been done for the complete aircraft.
In the end, a load database is obtained with the aim to deal with a various crash scenarii such as hard soil, water or obstacles. In this paper only an analysis of the ditching results is developed.

3 Load Database

3.1 Introduction

A load database is generated from the simulation of the ditching situation by ONERA (Radioss, SPH method). This database can be used for the design of innovative cabin features with the aim of improving passengers safety.

3.2 Load database definition

Figure 10 shows the positions of the different nodes used for each frame to record displacements and accelerations.

The location of the five studied sections are:
- Section 1 : Frame 23, row 1,
- Section 2 : Frame 35.5, row 12,
- Section 3 : Frame 46, row 20,
- Section 4 : Frame 49, row 25,
- Section 5 : Frame 62, row 33.

In the database, all the accelerations (filtered or not) and displacements are given for all the passenger seats from row 1 to row 34 (4 seats per row).

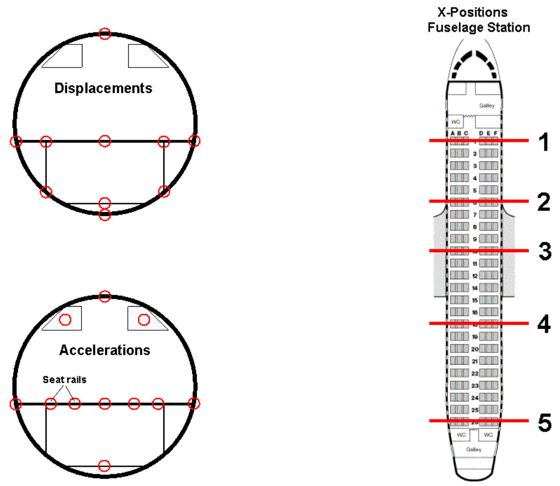
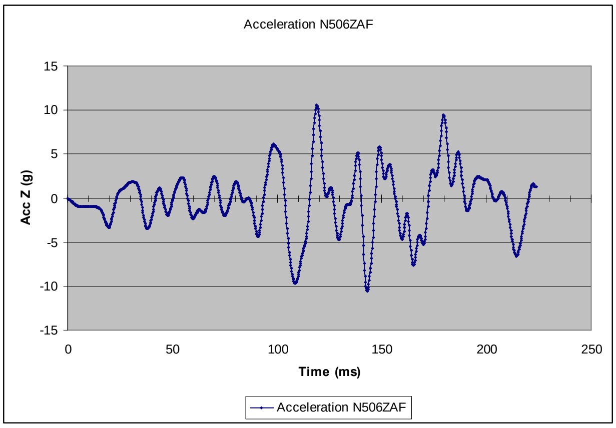


Fig. 10. Load database : Definition of the different sections

3.3 Analyse of results

The following figures present the different accelerations calculated in different sections of the aircraft. The simulation covers a time duration around 250 ms which permits to compare only three sections. In future works, simulations around 500 ms should give more results for the front part of the aircraft (second impact).



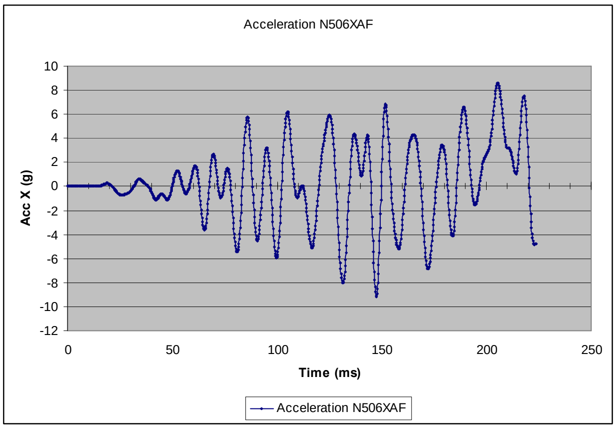
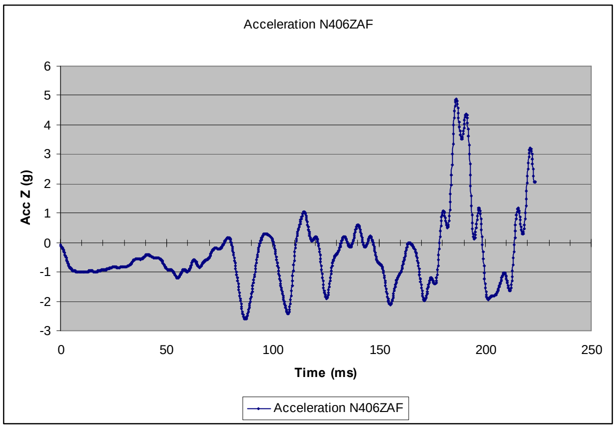


Fig. 11. Passenger accelerations in Z and X direction on section 5



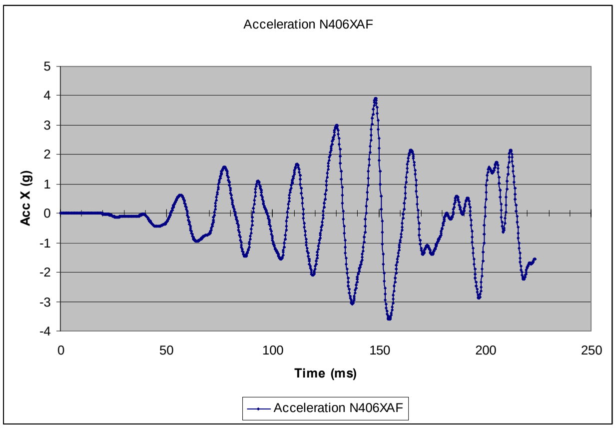
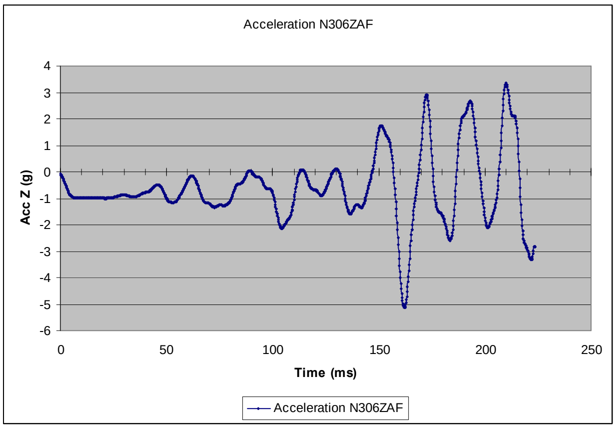


Fig. 12. Passenger accelerations in Z and X direction on section 4



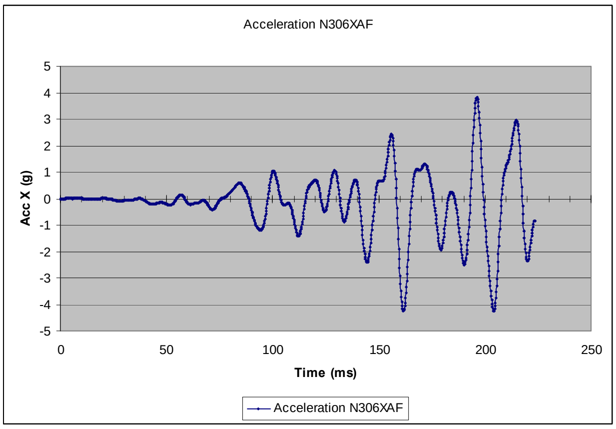


Fig. 13. Passenger accelerations in Z and X direction on section 3

A comparison between the three sections located at the rear part shows a maximum filtered acceleration in the vertical direction (Z)

around 10 g and 8 g in the horizontal direction (X) for section 5. This corresponds to the first impact. For sections 4 and 3 accelerations decrease around 5g. This level of acceleration can be considered to be satisfactory respectively to passenger safety considerations.
These results permit to run parametric case to improve passenger survivability and reduce fatality rates.

4 Conclusion and perspectives

As it has already been previously mentioned, the final goal of this work was to show that a numeric modelling by finite elements or SPH approach for ditching simulation was feasible. Indeed, thanks to the considerable progress accomplished in hardwares and computer tools, notably with the apparition of parallel computers, one could consider to refine the distribution of particles (SPH approach) without having serious consequences on the CPU times.
The time necessary to simulate the ditching phenomenon with the SPH approach (around 500 ms for 300 hours of calculus) is acceptable. The present top works on the modelling and numeric simulations of full F.E. ditching studies are very promising, especially in the domain of SPH methods. Nonetheless, other works are still necessary to quantitatively validate SPH fluid models and are in progress at ONERA/DMSE.

References

[1] Ortiz R., Portemont G. *Report on 3D F.E. simulations of the background data with ALE and/or SPH methods.* Rapport ONERA-Lille CRAHVI, RT 3/05368 DMSE, February 2002.

[2] Ortiz.R, Portemont.G, Charles J.L, Sobry J.F Assesment of explicit F.E. capabilities for full scale coupled fluid/structure aircraft ditching simulations 23rd Congress of ICAS, Toronto (Canada), september 08-13,2002.

[3] MalherbeB, Langrand B, Charles J.L, Sobry J.F. Improvement of crash models of large aeronautical structures. 22nd ICAS Congress, Harrogate (Great-Britain), August 28 September 01.

[4] P.W Randles, *Smoothed Particle Hydrodynamics: Some recent improvements and applications*, Computer methods in applied mechanics and engineering, 1996. [6] Monoghan J.J. Smoothed particle hydrodynamics. *Annu. Rev. Astron. Astrophys*, vol.30, pp.543-574, 1992.

[5] Randels P.W., Liberski L.D. Smoothed particle hydrodynamics : some recent improvements and applications. *Comput. methods apll. mech. engrg*. vol. 139, pp.375-408, 1996.

[6] Swegle J.W., Hicks D.L., Attaway S.W. Smoothed particle hydrodynamics stability analysis. *Journal of computational physics*, vol. 116, pp.123-134, 1995.

[7] Portemont G., Ortiz R., Deletombe E., Markiewicz E., Drazétic P. *Methodology for comparison of the contact pressure between experiment and FE models for coupled fluid/structure problems*. SUSI 2002, May, Montréal.

[8] Flodrops J.P., Deletombe E. *Improved ship design for marine safety : Extreme load effects and hydroelastic coupling.* Rapport ONERA-Lille SEAWORTH BRPR-CT97-0464, classification Code: TEC-C032-01, 1999.